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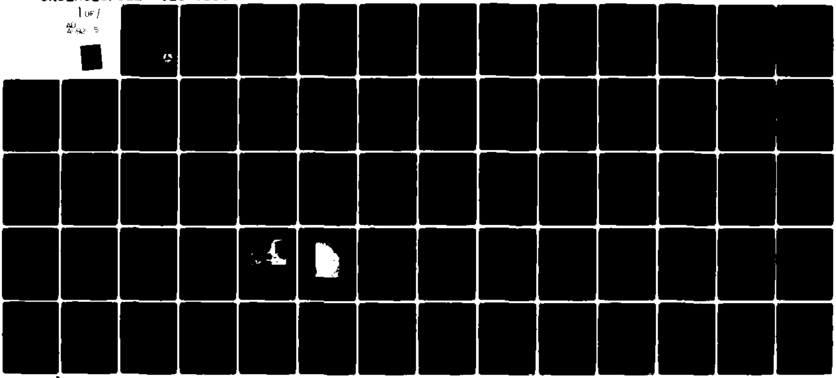

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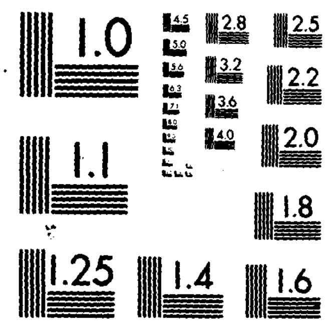

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LEVEL II

SIMULATION OF COAST GUARD VESSEL TRAFFIC SERVICE OPERATIONS BY MODEL AND EXPERIMENT

SEPTEMBER 1980

U.S. DEPARTMENT OF TRANSPORTATION

RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER • CAMBRIDGE MA 02142

PREPARED FOR UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT • WASHINGTON DC 20593

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16. Abstract

A technique for computer simulation of operations of U.S. Coast Guard Vessel Traffic Services is described and verified with data obtained in four field studies. Uses of the technique are discussed and illustrated. A field experiment is described in which Vessel Traffic Service watchstanders were tested in simulated operations at traffic loads well in excess of routine levels. The strategies adopted are identified and discussed with regard to their implications for operating procedures and appropriate recommendations are offered.

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PREFACE

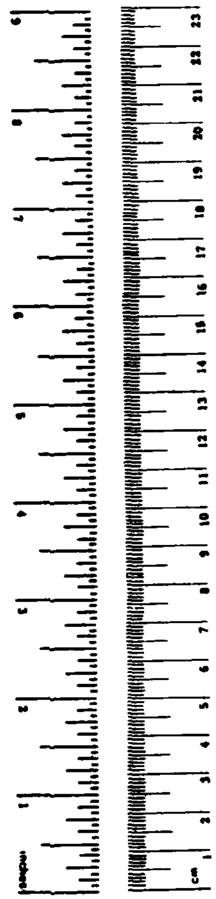
The Behavioral Systems Branch of the Department of Transportation's Transportation Systems Center (TSC) under the sponsorship of the U.S. Coast Guard's Office of Research and Development is conducting a series of studies of watchstander performance at Coast Guard Vessel Traffic Services (VTSs). This report describes efforts in Fiscal Year 1979 to simulate VTS operations by computer and experiment.

The authors wish to express their thanks to Mr. L. B. Kelley and LT P.R. Corpuz of the Office of Research and Development and to Dr. H.P. Bishop, Program Manager at TSC, for their contributions, guidance, and assistance. Special recognition is due Mr. B. Rothmel of Kentron of Hawaii, Inc., for assistance in data collection, to Mr. J.W. Royal of System Development Corporation for model development and programming, and to Mr. R. Rudich of TSC for assistance in data analysis. Finally, the authors are particularly grateful to CDR W.C. Park, III, LCDR R.F. Lutz, and the watchstanders of the Puget Sound VTS for their cooperation in planning and running the field experiment.

METRIC CONVERSION FACTORS

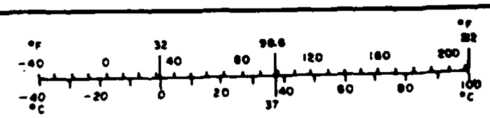
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

Two major efforts are summarized in this report: (1) development and evaluation of a model of Vessel Traffic Service (VTS) operations based on rate of information processing, and (2) exploration of the effects of unusual situations on the normal operating performance of VTS watchstanders.

MODEL DEVELOPMENT

A model of VTS operations, based on the rate of information flow through the system and programmed to permit simulation of operations with a computer, is described (2.1)*. Use of the model to predict the effects of changes in workload, equipment, procedures or personnel is proposed and illustrated using a model of a hypothetical VTS (2.2). The procedures used to convert data on operations to a model of the operation are given in detail for each sector of each VTS (2.3), and the results of simulation runs of each model are presented in support of the conclusion that the models do yield descriptive functions that are representative of operations at the VTSs (2.4, 2.5).

WORKLOAD STUDIES

To evaluate alternative approaches to the estimation of effects of exceptionally heavy workloads and other unusual events on the operation of VTSs, four VTSs (Houston, New Orleans, Puget Sound, and San Francisco) were surveyed. Information was sought on available data on past incidents, anticipated future events that would create heavy work loads, procedures for conducting and recording post-incident critiques, and the feasibility of conducting on-site simulation studies.

The results of the survey led to the conclusion that the kind of information required could only be obtained through on-site simulation (3.1). Consequently, an experiment was run at Puget Sound VTS in which ten subject watchstanders at a simulated communicating position were subjected to increases in vessel traffic load well in excess of normal operating conditions (3.3). The results of a one-hour run with each of the ten subjects demonstrated clearly that they were all forced to adopt strategies for effecting a tradeoff between the time spent communicating with vessels and the time spent plotting vessel positions, and that every watchstander adopted a different set of strategies (3.4.5). There was some evidence of increasing physiological stress during the course of the experiment, and the results showed a tendency for those subjects showing the least stress reaction to cope most effectively with the workload (3.4.6). This variability in response to unusual conditions and the desirability for a calm reaction were interpreted as evidence for a need for more stringent standing operating procedures (SOP) for unusual conditions and more initial and refresher training in such SOP (3.5).

Short interviews with the ten subjects yielded data suggesting that job satisfaction had improved over the previous year at PSVTS, but that some watchstanders still feel that a VTS assignment does not advance a career as a radarman or quartermaster (3.5.3.2).

RECOMMENDATIONS

The efforts described in this report, combined with information derived from earlier studies, suggest several efforts that warrant consideration. The feasibility and desirability of implementing these recommendations cannot be determined by TSC; however, the ideas seem worthy of note and further study.

1. Validate the procedure for modeling VTS operations by creating a preoperational model of operations using a new input/output terminal at Houston-Galveston VTS, exercising this model on a computer to derive operational descriptions, and comparing these descriptions with data collected on-site at HGVTS after the system has been in operation for three months or more.

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*Numbers in parentheses refer to sections of this report.

2. Institute at every VTS a program of study of possible unusual events (such as heavy traffic loads, accidents and incidents, equipment failure, and others). Determine alternative ways in which watchstanders might respond to these events; estimate the risks involved in each mode of response, and select the most desirable response mode.

3. Write clear, concise, and explicit procedures for each response mode selected as most desirable, and promulgate these as standing operating procedures (SOP).

4. Include knowledge of, and practice in, SOP for unusual events as an integral part of on-the-job training for VTS watchstander qualification.

5. Establish requirements for periodic refresher training in SOP for unusual events for all qualified watchstanders.

6. Program and implement group exercises that simulate unusual events, and include these exercises in the required refresher training program.

7. Be cautious in basing changes in SOP on studies evaluating watchstander stress. If feasible, base stress evaluations on professional evaluation of rates of hormone excretions in urine samples taken during the study. If urinalysis is not feasible, use the change in blood pressure as a criterion of stress. Do not depend on changes in pulse rate, analysis of voice recordings, or subjective stress estimates as criteria of stress unless the study has been preceded by extensive validation of these techniques.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

1.1.1 Purpose

The United States Coast Guard (USCG) operates six Vessel Traffic Services (VTSs), located at San Francisco, CA, Seattle, WA, Houston-Galveston, TX, New Orleans, LA, Valdez, AK, and New York, NY. At each VTS, enlisted watchstanders operate a 24-hour watch over vessel traffic within their assigned VTS area, maintaining an up-to-date plot of traffic conditions, informing each vessel of anticipated traffic situations, and adding such cautionary or directive advice as the situation warrants. The purpose of this operation is to reduce the probability of vessel collisions, groundings and rammings by informing mariners, particularly vessel masters and pilots, of impending traffic and other hazards in time for the mariners to take appropriate actions for safe passage. Such services are expected to reduce shipping-related hazards to environment and safety.

Since the effectiveness of VTS operations is highly dependent on the performance of VTS watchstanders, the USCG Program Office, Office of Marine Environment and Systems (G-WLE-2), authorized the Office of Research and Development (G-DST-3) to manage a program of study of VTS watchstander performance. In turn, the Behavioral Systems Branch of the Department of Transportation's Transportation Systems Center (TSC) was commissioned to conduct the studies, beginning in the second half of Fiscal Year 1977 (FY77).

The ultimate objectives of this program are:
(1) to develop models of VTS watchstander performance and effectiveness for use in analyzing and evaluating current operations and predicting future personnel and equipment needs;
(2) to determine requirements and make appropriate recommendations on personnel selection and training, and
(3) to employ research results as soon as they are developed to improve current operations and assure that future system designs are responsive to the needs of the people who must operate them.

The purpose of this report is to document the studies completed under this program during FY79.

1.1.2 Scope

This report reviews briefly the basic nature of VTS operations (Section 1.2, below), the results of research on VTS watchstanders prior to FY79 (1.3) and highlights of the FY79 studies (Section 1.4). Section 2 summarizes the progress made in modeling VTS operations to reflect watchstander performance and describes potential applications of the models. Section 3 reviews efforts to estimate the effects of unexpected events, emergencies, and excessively heavy workloads on VTS operations, including the details of an experiment conducted at the Puget Sound VTS (PSVTS) simulating very heavy workloads. Section 4 summarizes the conclusions drawn from FY79 studies and offers appropriate recommendations.

1.2 VTS OPERATIONS

No two VTSs operate in exactly the same way. However, the watchstanders all perform the following functions: communicating, monitoring, and plotting. Although these functions often overlap in various activities, we have attempted to treat them separately for purposes of analysis.

Communicating involves two-way conversations between VTS watchstanders and mariners within the VTS area, conducted almost exclusively via VHF-FM radiotelephone. All VTSs have their own transceiver sites, and most have VHF-FM channels assigned exclusively for VTS use.

Monitoring involves the information processing conducted by VTS watchstanders to predict future traffic situations and to determine courses of action.

Active Monitoring covers activities that can be detected and measured by human observers or automatic equipment. Active monitoring includes the visual scanning of traffic plots, equipment displays and printed references, as well as the operation of equipment to select or modify information sources.

Passive Monitoring involves internal processes, such as looking at displays without moving, listening to the radio, integrating and projecting traffic information, evaluating hazards and deciding on courses of action. Passive monitoring can only be inferred from observation; it can not be differentiated from inattention or distraction from the task. In spite of this difficulty, however, it is a basic function of watchstanders and is a major focus of attention in our analysis of watchstander effectiveness.

Plotting encompasses those activities that translate incoming information into a picture of the vessel traffic situation in the VTS area. Inputs include position reports made by mariners or (sometimes) human observers via VHF-FM radiotelephone and displays of the returns from surveillance devices (radar and television). Plots include vessel models on map tables or boards, radar displays (sometimes with grease pencil data added), or computer-generated map displays and data lists. Activities considered as part of the plotting function include preparing and modifying vessel models, placing and replacing vessel models on the plot, preparing and manipulating vessel data cards, marking radar scope faces, adjusting radar and television equipment to obtain data for the plot, and entering data into a computer.

Additional miscellaneous activities performed in VTSs include record keeping, reporting, and (in quiet periods) a variety of activities not directly related to the operation (e.g. eating, reading, conversing).

The resources and methods for performing VTS functions vary considerably among the current VTSs. Table 1-1 summarizes some of these differences that existed during the period of this report (FY79).

1.3 RESULTS OF PREVIOUS WORK

1.3.1 General Accomplishments

During FY77 and FY78, the work of VTS watchstanders was analyzed in detail at four sites (Houston, Seattle, New Orleans and San Francisco). Operations were observed; activities were logged and timed; work space and equipment were photographed; voice communications were tape recorded, and vessel traffic summaries were obtained. The results of data analysis for each VTS were published in separate interim reports (References 1, 2, 3, 4) and were combined into a final report (Reference 5), which provided a general description of VTS watchstander duties, discussed problems in communications, equipment and operation, and offered appropriate recommendations.

1.3.2 Model of VTS Data Flow

The observations made during the studies of the VTSs led to the formulation of a model of VTS operations based on the rate of flow of information through a vessel traffic center (VTC). The model is stochastic in nature...that is, the sequence of events and the amount of time involved in each event are both described as probability distributions. The data collected at each VTS provided a sampling data base, and a set of commercially available programs, the General Purpose Simulation System (GPSS), made it possible to exercise the model on a computer to simulate VTS operations under various conditions. Initial GPSS runs on a subset of the FY78 data base produced results that were consistent with observed operations, indicating a basic validity to the modeling process.

Both the flow of events and the event duration data in the model were based on observations and measurements made under routine operating conditions. Therefore, it was concluded that the next step in model development should be to learn as much as possible about the way watchstander performance might be expected to change under unusual or unexpected conditions (such as excessively heavy workloads and emergency situations) and to modify the model to account for such conditions. A second objective was to utilize all of the data in the FY78 data base to make an individual model of each sector of each VTS studied.

TABLE 1-1. CHARACTERISTICS OF CURRENT VTSs

VTS	H-G	NO	PS	SF	PWS	NY*
Assigned Radio Channel	12	11,12,14	14	13	13	11,12,14
SURVEILLANCE						
Radar Sites	1		4	2	2	2
Television Sites	4					5
Human Observers		X				
PLOTTING AND TRACKING						
Table and Board			X			
Board and Radar	X**		X**	X	X	
Computer	X	X				X
Data Cards	X		X	X	X	
VESSEL MOVEMENT						
Reporting Mandatory			X		X	X*
Reporting Voluntary	X	X		X		
Traffic Separation (TSS)			X	X	X	

H-G: Houston-Galveston VTS, Houston, TX
NO: New Orleans VTS, New Orleans, LA
PS: Puget Sound VTS, Seattle, WA
SF: San Francisco, VTS, San Francisco, CA
PWS: Prince William Sound VTS, Valdez, AK
NY: New York VTS, New York NY

*NYVTS was not operational during the period of study.
**Radar backup to plot.

1.3.3 Problems of System Stress

The limitations of the data based on routine operations extended beyond their implications for modeling to such considerations as operational procedures, personnel selection and training, and requirements for equipment. An immediate, high priority need at the end of FY78, then, was to determine the characteristics of VTSs operating under stress. There was little, if any, information readily available. The VTSs had rarely experienced stress, and the stressful incidents that had occurred were not documented. Thus a data collection task regarding system stress was clearly indicated as a requirement for FY79.

1.4 HIGHLIGHTS OF THE FY79 STUDIES

The FY79 efforts included:

1) Refinement of VTS models to reflect all of the data collected in FY79 and new data on system stress,
2) Development of a program for selection and training of VTS watchstanders,
3) Evaluation of data processing and display requirements to reflect the functional needs of VTS watchstanders, and
4) Initiation of a program for evaluating user reactions to VTS services. The last three efforts are incomplete, ongoing projects whose progress in FY79 was documented internally. The modeling accomplishments of the first effort are documented in Section 2 of this report, and the studies of system stress are summarized in Section 3.

2. MODELING VTS OPERATIONS

2.1 BACKGROUND

2.1.1 Introduction

This section describes the development and verification of the completed computer models of typical VTS operations at San Francisco, Puget Sound, New Orleans, and Houston-Galveston. It also contains an explanation of the entire modeling process -- development and output, verification, validation, and applications -- illustrated by a simplified example of VTS operations.

The description of the development and verification procedures are contained in two subsections: Method of Development and Results. The methods employed in gathering field data, preparing it for the model, and construction and computer programming of each model are covered in the first section. The second describes the results of the development of these computer models in terms of data base size, computer requirements and comparisons of simulation output with field data to verify each. Discussion and conclusions follow.

2.1.2 VTS Operations

A VTS is a system of equipment and personnel which receives information about vessel traffic in a defined area, processes the information, and informs vessels in the area of conditions affecting safety and efficiency of transit. Detailed descriptions of VTS operations at each center can be found in References 1 through 4 and summarized in Reference 5.

Each reference presents a sound description of VTS operations for a different waterway. These reports document not only the equipment, procedures and personnel at each VTS, but also the duration and relative frequencies of the major watchstander activities performed at each VTS. These reports, then, provide the basic information for development of the models and should be referred to for information on VTS operations, the methods employed in gathering the field data, their analysis and results.

2.1.3 Modeling Requirements

To accomplish his task, the watchstander interacts with equipment according to established procedures or sequences of steps. Each step takes time with an accompanying delay until the next step begins. Some steps generally take longer than others. In any given hour a watchstander may do more of some activities and less of others depending, mostly, on the frequency and type of mariner requests.

Obviously human behavior is highly variable. Timing a person's performance of the same task several times will produce a series of task durations, and timing a second person's performance at the same task will yield a different series of durations. Consequently, each of the durations required for a watchstander to perform each step of a procedure and the delays between steps will probably differ from instance to instance.

The modeling technique employed should be capable of reflecting the procedures, the steps comprising the procedures, the variabilities in durations for each step and the accompanying delays between steps, and the relative frequencies of activities as determined by mariner requests. To be fully useful to the U.S. Coast Guard, the completed models should be amenable to rapid modification for the study of increased vessel traffic workload and changes in equipment, procedures and personnel. Therefore, they should be suited to computer programming and simple, accurate simulation.

Finally, the output obtained from the computer simulation of a model must be sensitive to changes in system inputs to be indicative of VTS system and watchstander performance.

2.1.4 GPSS Computer Modeling Package

The General Purpose Simulation System (GPSS) is a commercially available software package combining the above features into an easily used computer format. It is a user-oriented, high-level language, computer software package designed for the modeling and simulation of a flow (in this case, of information) through a system using a logical progression of steps. One step may always be followed by another or by any one of several alternative steps. A given step may delay the flow for a fixed or a variable interval of time. The model, then, is a network of procedural steps, each delaying the flow of information for a time and interconnected according to the logic underlying the flow of information.

The inputs for computer simulation of a VTS using GPSS are a model of the step-by-step logical flow of information accompanied by the statistical distributions of delay times for each step and the statistical probability or relative frequency of one step or series of steps following another. The actual computer simulation is driven by the statistical distribution of intertransaction times (time from one vessel calling in on the radio until the next call). Outputs include average delay times for a step or series of steps, number and average duration of delays for various steps or series of steps, and proportion of time available for various series of steps. Changes to the logic of a given model are made simply by substituting different steps or series of steps accompanied by their delay times and relative frequency of occurrence.

2.2 ILLUSTRATION OF MODELING TECHNIQUES

2.2.1 Introduction

The purpose of this section is to use a simplified example of VTS operations to illustrate how a VTS model is developed, programmed and simulated. The practical implications of the output data from the computer simulations and their use in model verification and validation will be discussed. Simplified examples of some of the applications in the areas of workload and changes in equipment, procedures, and personnel will be presented. In an actual VTS there would be many more steps included than are presented in this example.

2.2.2 Data Gathering

a) Documentation. The first step in developing a model for our illustrative VTS is to obtain documentation describing the procedures and equipment at the VTS. Our VTS has a VHF-FM radio, vessel status cards, and a computer which displays a map of vessel positions updated periodically.

The center's formal documented procedures indicate that the watchstander will perform both demand and monitoring activities. The demand activities in this example consist of handling either check-in calls or check-out calls. The monitoring activities performed by the watchstander will be either to generally survey overall vessel positions or to check upon a particular vessel. The documentation describes the procedures by which these activities are to be accomplished. The watchstander must proceed through a logical sequence of steps involving interactions with the equipment.

These activities and the procedures the watchstander goes through to accomplish them are then incorporated into a block diagram as presented in Figure 2-1. This particular example contains only a few of the actual steps involved at a real VTS. This diagram shows the two major types of watchstander activities: demand and monitoring. It shows the steps by which different types of demand activities are accomplished and the interconnections between the various component procedures at this VTS. The block diagram reflects the following VTS operations.

A pilot calls in initiating a demand activity by the watchstander. The type of demand activity, check-in or check-out, is determined by the pilot's request, "This is a check-in call" (Step 1, Figure 2-1). The watchstander then handles this type of demand activity according to established procedure. After receiving the pilot's check-in call, the watchstander acknowledges it (Step 3). The watchstander keys the data describing the vessel (its position, speed, destination, estimated time of arrival, etc.) into the computer, and waits for the display to appear (Step 5). Then

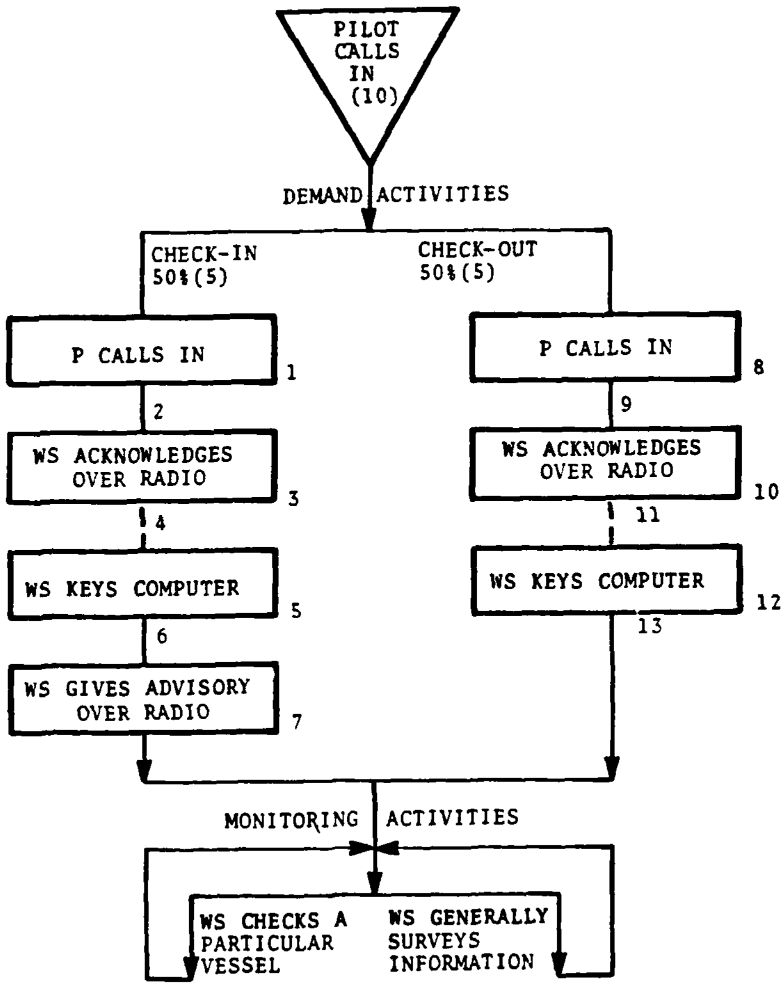

FIGURE 2-1. SIMPLIFIED EXAMPLE OF VTS OPERATIONS

the watchstander gives the pilot an advisory over the radio (Step 7). Intervening Steps 2, 4 and 6 account for the delays which inevitably occur between procedural steps.

If the pilot had requested to check out of the system (Step 8), the watchstander would proceed through a different series of steps. The watchstander would acknowledge this call over the radio (Step 10). Then the watchstander would enter the vessel's name or code into the computer and remove the vessel from the system (Step 12). Again, steps 9, 11, and 13 account for delays.

When not engaged in demand activities the watchstander would be involved in monitoring; either in general or checking a specific vessel. The actual steps involved are not presented here to keep this example uncluttered. Both monitoring tasks are interruptable by a pilot's call over the radio.

At this point in constructing a model of VTS operations we do not know if, in fact, watchstanders always follow the procedures according to the steps described in the documentation. We do not know how often pilots call to check-in or to check-out. We do not know how long each step takes or how long a delay occurs between steps. For instance, two pilots may call the VTS to check-in; one call may take only a few seconds because the pilot supplies all the request information immediately, while a second pilot may give only the vessel name, requiring the watchstander to ask for the other needed information. After the pilot calls in, the watchstander may be able to respond almost immediately or he may be attending to something else and require slightly longer to respond. Certainly his response time will not be the same for each radio call.

b) Field Data. This unknown information is acquired during a field trip to the VTS. The steps in the block diagram are verified through discussions with both watchstanders and watch officers and by extended observations of watchstander behavior. Revisions are made to reflect the actual working procedures. Usually such revisions are minor.

The majority of the field work concerns gathering data to determine the relative frequencies of activities, the time required for performance of each step, the delay until initiation of the next step, and the time pilots call the VTS.

Suppose, for an hour of data gathering, ten calls come into the VTS over the radio from pilots. The hour starts at the beginning of the first call. The next call starts 360 seconds later, goes to completion, then there is a period in which no calls come. The third call starts 300 seconds after the second call started. Each call begins a transaction between the pilot and the watchstander over the radio. These times are the interinitiation intervals, the time between the initiation of one transaction and the initiation of the next. The interinitiation intervals for our example are listed in Table 2-1.

If the number of incoming radio calls per hour were lower, then these interinitiation intervals would be greater. If the number of incoming radio calls per hour were greater, then the interinitiation intervals would be smaller. Weather, the harbor geography and the number of vessels in the system all determine the interval between incoming radio calls and, consequently, the watchstander's incoming workload.

Of these ten radio transactions, five happen to be pilots requesting to check-in and five to check-out. Consequently, there is a 50-50 split at the first branch point in Figure 2-1. Table 2-2 presents the durations of and between each step for each of the radio transactions. For the first check-in call the observer records 3 seconds for the pilot to make a call-in over the radio (Step 1, Figure 2-1 and Table 2-2). There is a 1-second delay until the watchstander can respond (Step 2). The watchstander takes 4 seconds to acknowledge the pilot's call over the radio (Step 3). Other times would be recorded (Step 4), but are not included in this simplified example. The watchstander takes 20 seconds to key the vessel name, pilot i.d., vessel destination, speed, estimated time of arrival, etc. into the computer (Step 5). There is an 8-second delay before the computer displays the instruction needed by the watchstander to give an advisory (Step 6). The watchstander then takes 10 seconds to give the advisory over the radio (Step 7). As shown in Table 2-2 the time required at each step in the communication procedure often varies from one call to the next.

TABLE 2-1. TYPES OF TRANSACTIONS AND INTERINITIATION TIMES FOR EXAMPLE VTS

NO.	TYPE	TIME (SEC)
1	Check-in	360
2	Check-in	300
3	Check-out	420
4	Check-out	340
5	Check-in	380
6	Check-out	330
7	Check-out	310
8	Check-in	390
9	Check-out	410
10	Check-in	--*

*Since the hour ends before the next radio transaction begins, this interinitiation time is indeterminate.

TABLE 2-2. DURATION OF PROCEDURAL STEPS FOR EACH RADIO TRANSACTION
(Seconds)

Check-ins

Procedure/Step No.

Call No.	P Calls In 1	2	WS Acknowledges 3	4	WS Keys Computer 5	6	WS Gives Advisory 7
1	3	1	4	-	20	8	10
2	2	1	3	-	15	12	12
5	4	2	5	-	23	6	15
8	1	1	2	-	18	9	18
10	5	0	2	-	21	10	14

Check-outs

Procedure/Step No.

Call No.	P Calls in 8	9	WS Acknowledges 10	11	WS Keys Computer 12	13
3	4	2	3	--	7	7
4	2	2	4	--	8	11
6	3	1	2	--	12	5
7	1	0	5	--	9	8
9	5	3	2	--	10	9

P = Pilot

WS = Watchstander

Similar data for check-outs are recorded in the bottom of Table 2-2. Again, each step in the procedure for this type of demand activity is assigned a number and the duration of each instance is tabulated.

For the first check-out call, the observer records 4 seconds for the pilot to make the call over the radio (Step 8). There is a 2-second delay until the watchstander responds (Step 9). The watchstander takes 3 seconds to acknowledge the pilot's call over the radio (Step 10). Other times are recorded (Step 11). The watchstander takes 7 seconds to key in the information required to check the vessel out of the computer system (Step 12). There is a 7-second delay before the computer displays the confirmation that the vessel is checked out.

At this point, we know the relative frequencies of the two different types of demand activities, check-ins and check-outs. We also know the time required for performance of each step and the delay until the initiation of the next step for each call-in. Finally, we have determined how often pilots call into this example VTS.

When demand activities are completed the watchstander has time available for both monitoring activities: checking upon a particular vessel and generally surveying the available information. Both of these types of monitoring activities can be interrupted by a pilot calling in. Observation of what the watchstander does when not responding to calls indicates that 20% of monitoring activities involve checking a particular vessel, 80% involve general surveillance. To keep this example uncluttered, no steps descriptive of the two types of monitoring activities are included.

The data gathering for the model is complete. The activities and the procedural steps to accomplish each have been determined. The relative frequencies of types of activities and the durations of each step in the procedures have been recorded for each instance. The intervals between arrivals of radio calls by pilots have been recorded again for each instance. Now the model can be constructed, programmed and computer simulated.

2.2.3 Model Construction

The model of VTS operations has already been presented in the block diagram in Figure 2-1. This diagram shows the types of activities and the procedural steps required to accomplish them in numbered blocks. The lines connecting the blocks indicate the sequence and interconnections of these steps. As noted above, the data have already been recorded and a table is prepared for each numbered block or interconnecting line. Each such table contains the times listed in one column in Table 2-2. The relative frequencies at branch points have been determined from the field data and entered onto the block diagram. The input to the VTS operation, the time intervals between incoming radio calls and their types, have been tabulated in Table 2-1.

This block diagram and the supporting data base constitute the model of VTS operations. This model describes the flow of information through the VTS in terms of watchstander interactions with both the pilots and the available equipment in accordance with observed operating procedures. To be useful, however, this model must be programmed for computer simulation.

2.2.4 Computer Entry

The block diagram and its supporting data base are turned over to the programmer for entry into the GPSS computer package. The programmer redraws the block diagram using the GPSS symbology. This new diagram permits easier step-by-step entry of the blocks and their interconnections into the program. The programmer then translates this new block diagram into the required GPSS listings, enters the relative frequencies at branch points, and tabulates the data for each block or interblock interval. The intervals between radio calls are also tabulated. These listings are then checked for errors and edited. The model can then be simulated in the computer.

2.2.5 Simulation

The computer simulates VTS operations by a Monte Carlo technique. This technique employs a random number generator built into the GPSS program to select values from the

various tables entered into the program. In conducting a simulated hour of our example VTS, the program would first go to the table of interinitiation times (Table 2-1) and, at random, select a time until the next radio call would come into the system. Suppose entry no. 5, 380 seconds, was selected, then nothing would happen until 380 seconds had passed. At that time the watchstander would commence a demand activity. There is a 50-50 chance this call would be treated as a check-in. The selection of type of demand activity would be made at random by the computer, but on the average each type would be selected half of the time.

Once the check-in activity commences, the computer would go to the table for block 1 (see Table 2-2) and select, at random, from among the possible durations known to have been taken by a pilot to call for a check-in. It might pick 4 seconds or it could pick 1 second. Each time the computer comes to this table it will choose one value at random.

The computer then proceeds through tables for blocks 2 through 7 picking a number from each at random. For example, in a given simulation, the computer might pick 4 seconds for block 1, 1 second for 2, 5 seconds for 3, 15 seconds for 5, 6 seconds for 6 and 10 seconds for 7. Totaling these numbers yields 41 seconds to process this check-in call.

The computer then goes into monitoring activities until the next radio transaction begins 380 seconds after the first radio transaction began.

The next time a pilot is to call-in, the computer picks number 2 from Table 2-1, 300 seconds. And this call becomes a check-out. The computer proceeds through numbers 8 through 13 (see Table 2-2) as it did before, picking 4 seconds, 2 seconds, 10 seconds, 7 seconds, and 9 seconds for a total of 32 seconds to complete a check-out call.

After going through this simulation for a period of 3600 seconds (one hour) the operation has been simulated enough times to yield a reliable output indicative of watchstander performance and VTS operations.

2.2.6 Output

After simulating VTS operations for an hour, the same duration over which field data was acquired, the computer has stored considerable data summarizing operations. A sample output from the hypothetical VTS is presented in Table 2-3. This subsection discusses these output data and their relationship to actual VTS operations.

In Table 2-3, the input to the model is the number of call-ins per hour or the rate at which pilots would call-in to an operating VTS. This rate is determined by the vessel traffic in the harbor at the time, their relative positions in the harbor, and conditions such as weather which affect navigation. In the case of this example the number would be 10 call-ins an hour.

The output from computer simulation of a model for an hour can be described in several useful ways as discussed below. The average utilization indicates how the watchstander's time was divided between demand and monitoring activities. In our example, the watchstander spent 10.4% of the simulated hour involved in demand activities and had 89.6% of the hour available for the performance of monitoring activities. Both activities are significant to the proper functioning of a VTS. However, demand activities do supersede monitoring activities. At some point, though, a watchstander can become so involved just responding to demand activities that no time remains for review of the overall harbor situation. A watchstander's effectiveness then becomes questionable; important information could be unintentionally missed and subsequently left out of an advisory slowing transit or contributing to a safety hazard.

The average processing time per demand activity is obtained simply by dividing the total number of seconds in the simulated hour during which the watchstander was engaged in demand activities by the number of call-ins responded to. This average indicates the amount of time both pilot and watchstander spend engaged in a complete radio transaction. In our example this average is 37.5 seconds, a reasonable time.

The number of interruptions of monitoring activities indicates how often the watchstander was interrupted by an incoming radio call while performing some monitor-

TABLE 2-3. SAMPLE SIMULATION OUTPUT FROM EXAMPLE VTS INPUT

INPUT	
No. of Call-ins Per Hour: 10	
OUTPUT	
Average Utilization	
Demand Activities	10.4%
Monitoring Activities	89.6%
Average Processing Time per Demand Activity	37.5 sec
Number of Interruptions of Monitoring Activities	6.
Call-ins Delayed	
Check-in	2.
Check-out	3.
Total Number of Call-ins Delayed	5.
Average Delay Time	30.0 sec

Demand Activity Durations (sec)

Activity	Number	Mean	Std. Dev.	Total Duration
Check-in	5	45.00	6.221	225
Check-out	5	30.00	10.114	150

ing activity step. Too many interruptions may also be detrimental to the overall effectiveness of VTS operations. In our example the watchstander was interrupted 6 times during the simulated hour.

The number of call-ins that were delayed is broken down by category so that in our example two check-in calls and three check-outs were delayed which results in a total of five delayed calls. The computer also totals the number of seconds these call-ins were delayed and computes an average delay time. These delays can occur when a watchstander is already occupied in demand activities in response to a pilot when another pilot calls in. The second pilot is then delayed. In the case of our example, 5 pilots had to wait an average of 30 seconds until responded to by the watchstander. It is important to keep the frequency and duration of these delays to a minimum if possible, i.e., to interfere as little as possible with pilot operations.

The demand activity output statistics summarize the watchstander's overall performance of the steps involved in responding to call-ins. These statistics are the number of instances of each type of demand activity, the mean and standard deviation of the durations of these instances and the total duration out of the simulated hour occupied by each activity. The mean is simply an average obtained by dividing the total duration by the number of instances. The standard deviation is an index of the variability of the data about the mean. A small standard deviation indicates little variability about the mean indicating a reliable, stable measure. A large standard deviation indicates considerable variability about the mean. The average duration of the five check-ins in our example is 45 seconds with a standard deviation of 6.2 seconds. These five total 225 seconds out of the simulated hour. Similarly, the average for the five check-outs is 30 seconds with a standard deviation of 10.1 seconds, totaling 150 seconds out of the hour. These two totals combined equal the 375 seconds which account for the 10.4% of the simulated hour in which the watchstander was involved in demand activities.

2.2.7 Verification

The verification process checks for errors in both model construction and computer entry. The premise is that simulation results should not differ greatly from the field data upon which the model was developed. If they do, then there must be an error in either model construction or computer entry. A criterion must be established, though, as to how much of a difference can be tolerated. The following paragraphs describe the verification technique employed based on a criterion employed in the computer modeling field.

Because of the statistical nature of both simulation and field sets of data exact duplication of results cannot be expected. There must, however, be limits to the discrepancies which will be tolerated. A criterion based on work in the field of computer simulation of human behavior (Reference 6) was chosen before the VTS computer models were simulated. According to this criterion, the computer simulation results could err no more than one standard deviation from the field results (two standard deviations were employed in Reference 6). Standard deviation is an index of the variability from the mean for a set of data. Simplistically, data presumed to be similar falling within a one standard deviation spread on either side of the average of another set of data have a 68% chance of being equivalent. This criterion is tolerant of sometimes highly variable simulation results yet avoids acceptance of extreme simulation results as equivalent to field data.

Field data for the example VTS show 10 call-ins, half check-ins, half check-outs. Field data indicated an average of about 40 seconds were required for the watchstander to complete a check-in transaction and about 30 seconds for a check-out. Demand activities only took about 10% of the watchstander's time.

The simulation data in Table 2-3 show that for one simulated hour there were 10 call-ins, half check-ins and half check-outs: The simulated check-ins averaged 45 seconds plus or minus one standard deviation (6.2 seconds). The 40 seconds from the field data does lie between the 38.8 and 51.2 seconds criterion boundaries. Simulated check-outs averaged 30 seconds plus or minus 10.1 seconds, one standard deviation. The 30 seconds from the field data does lie between the 19.9 and 40.1 seconds criterion bounds. Simulated demand activities required 10.4% of the watchstanders time compared to about 8% from the field data.

The simulation results should agree with the field data within the criterion, as these example data do, provided there are no errors in either the programmed data base or construction of the blocks and their interconnections.

2.2.8 Validation

The overall technique, however, should be validated; that is, tested on an independent data base. This testing can be accomplished in either of two ways: The model can be constructed based on one set of data gathered at a field site, simulated, and the results compared to a separate set of field data gathered at the same site. Or a complete model can be constructed for a new site based on documented procedures and experience and data gathered at other sites. Computer simulation results for this new model should agree with actual data collected later at the site.

Validation is another method of assuring that the modeling technique employed is really descriptive of VTS operations.

2.2.9 Applications

Modeling VTS operations is useful in its own right as a way of describing those operations. The process of constructing these models brings out the processes which occur at a VTS and indicates the magnitudes involved in terms of time, frequency, and percents. Knowledge of both the processes and their magnitudes is useful in coming to understand the inner working of VTSs. However, significant further use can be made of these models.

By making changes in the rate at which radio calls come in to a VTS we can use computer simulation results to study the effects of increased workload. The effects of changes in equipment can be simulated by adding, moving, or changing the data base of particular equipment-related blocks in the flow diagram. Similarly, procedural and personnel changes can be simulated. The following paragraphs use our example VTS to illustrate how this technique of computer simulation of the models of VTS operations can be so applied.

a. Workload

Actually there are two questions concerning the effects of increasing workload due to traffic buildup:

1) What happens to VTS operations as the workload increases?
2) What workload can a watchstander safely handle?

Answers to the first question indicate potential weak points in a VTS operation by determining which system elements fail to keep up. Answers to the second question aid in determining safe workload limits for watchstanders and therefore, when further sectorization, with its increased costs in labor and equipment, is required. Increased workload, as far as a watchstander is concerned, means an increased rate of radio calls coming into the VTS from vessel and tug pilots initiating transactions. This increased rate imposes increased demands and decreases the amount of time available for monitoring activities. Some minimum level of monitoring activities is necessary for safe VTS operations.

An increase in the number of radio calls could be due to a specific incident such as increased traffic congestion at a particular location, or an overall increase in the number of vessels in the harbor. Regardless of the cause, the end result is an increase in watchstander workload.

The following paragraphs discuss how the computer modeling and simulation technique is employed in answering questions about system and watchstander limits under increasing workload.

The computer model of our example VTS is based on field data gathered during typical, everyday operations, but the computer model can be used to simulate atypical, abnormally high workloads in the following manner. A wide range of radio communication loads is generated by expanding or contracting the interinitiation interval (Table 2-1) obtained from the field data. Expansion is accomplished by multiplying each interinitiation interval to obtain fewer radio calls per hour; contraction is accomplished by dividing the same distribution to obtain more radio calls per hour. In this manner, the basic distribution of increasing radio calls is preserved while the effects of various communication loads are explored.

As the radio communication load increases from the 10 per hour of our example VTS, several output measures (Table 2-3) change: both the number of calls delayed and the associated average delay time per call increase. These two measures indicate

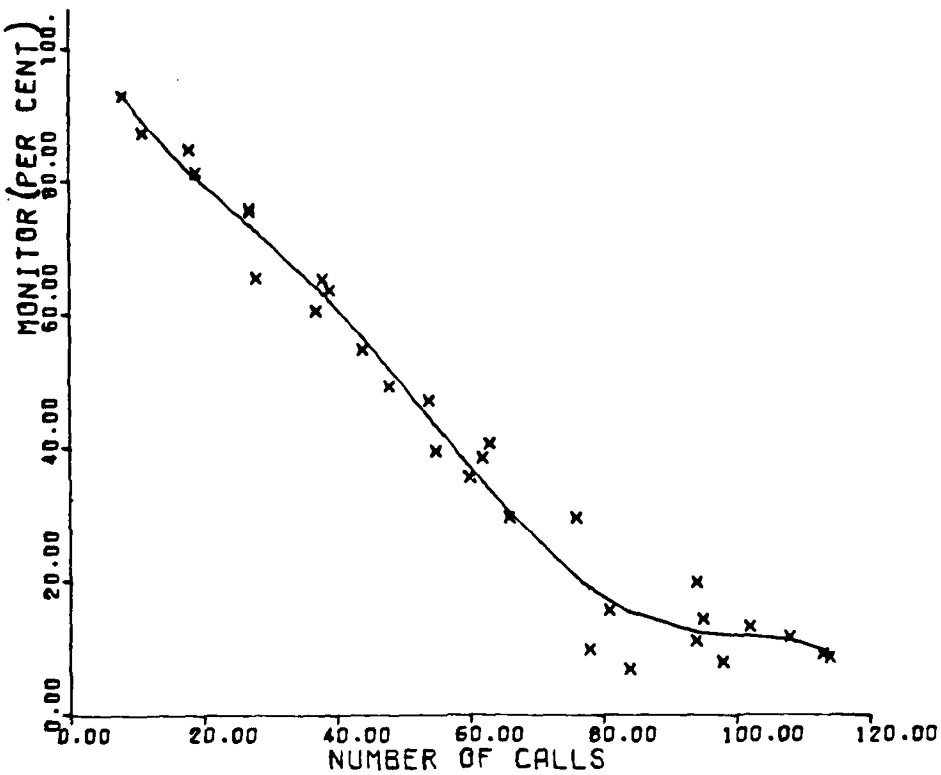

FIGURE 2-2. PERCENT OF TIME AVAILABLE FOR WATCHSTANDER MONITORING ACTIVITIES AS A FUNCTION OF THE NUMBER OF RADIO CALLS PER HOUR TO THE EXAMPLE VTS

that some system element (or step in Figure 2-1) is failing to keep up with the increasing workload thereby delaying more and more pilot calls longer and longer.

The raw GPSS output (not included in this report) can be examined to determine which system element creates the backup. For our example, as the radio communication workload increases, the simulation output indicates that the number of delays increase while the watchstander is checking-in another vessel. The raw GPSS output further indicates that the watchstander is most often occupied keying data into the computer (Step 5, Figure 2-1) when other pilots call in. Consequently this weak step or system element should be examined as a possible candidate for change. Possible changes might be the elimination of keying through use of other equipment, changes in procedure to bypass that step (second person responsible for keying and checking information), or reducing keying time (by requiring minimum keying speeds by watchstanders). These kinds of candidate changes are discussed in subsections b, c, and d below.

These paragraphs have illustrated, with the example VTS, how this computer handling and simulation technique can be employed to explore system limitations under increasing workload. The technique for explaining the second question, watchstander limits under increasing workload, is described in the following paragraphs.

An index employed in studies of system operator response to increasing workload is spare capacity (Reference 7). The assumption is that if an operator has some spare capacity he has not yet reached his workload limit. In our case the proportion of time a watchstander has available for monitoring activities is an indication of his spare capacity. However, some monitoring is required for safe VTS operations. How much may be determined from measures of watchstander performance decrements in an experiment simulating actual VTS operations. Experimental simulation of actual VTS operations permits accurate measures of watchstander performance during very high, controlled radio communication loads. Multiple computer simulations of the model can be used to relate the number of radio calls to the proportion of time available for monitoring.

For our hypothetical VTS, the number of radio calls is manipulated as described earlier. The results of these simulations of a wide range of radio communications loads is presented in Figure 2-2. Each data point relates the number of radio calls for one simulated hour to the proportion of time the simulated watchstander has available for monitoring activities as indicated on the computer monitor. For this example, the range of incoming radio calls extends from a low of 8 to a high of 114 calls per computer simulated hour. The corresponding proportion of time available for monitoring extends from 93.1% to 8.5%. A best-fit curve is plotted through the thirty data points in Figure 2-2.

In an experimental duplication of actual VTS operations, watchstanders at our example VTS were able to handle an average of up to 55 radio calls per hour before their performance (as measured by errors, delays, and inaccurate tracking) deteriorated significantly.

This number of radio calls, 55, translates, from the graph in Figure 2-2, to 40% of an hour available to the watchstander for the monitoring required for safe operations. We also know from the field data that the 10 radio calls recorded (Table 2-1) originated from the 4 vessels in the harbor at the time; so there was an average of 2.5 radio calls per vessel in an hour. Therefore a limit of 55 radio calls per hour implies, for this harbor, a limit of 22 vessels per hour for each watchstander.

In the study of the effects of candidate changes discussed below in subsections b, c and d, this criterion proportion of an hour available for monitoring, 40%, must be maintained. However changes in equipment, procedures and personnel will change the shape of the curve in Figure 2-2, possibly permitting a greater number of radio calls per hour and consequently a greater number of vessels per sector watchstander.

b. Equipment Change

Suppose that during the field data gathering trip to our example VTS, the data indicated long delays (up to 12 seconds) between the time the watchstander finished keying information into the computer and the time the new information was displayed. This long duration is reflected in columns 6 and 13 on Table 2-2 and at the same numbered points in Figure 2-1. Suppose further that this delay is intolerable and that a 1-second delay is the limit on both technical feasibility and watchstander tolerance. What would be the effect of improving the system so that the computer delay is only 1 second?

TABLE 2-4. DATA TABLES FOR ADDITIONAL BLOCKS DESCRIBING TIME TO FILL OUT CARD

Check-in Prior to 5	Check-out Prior to 12
17	2
23	3
20	1
25	2
24	1

TABLE 2-5. DATA TABLES FOR BLOCKS REFLECTING REQUIRED KEYING RATES

Check-in 5	Check-out 12
10	4
8	4
11	5
9	4
10	5

The computer program for the model is easily altered to reflect this change. Each number in columns 6 and 13 of Table 2-2 is replaced by 1 second. Running several computer simulations will then show, for this example, that with the same radio traffic load, where originally the watchstander had 10.4% of his total time occupied by demand activities, he now has 7.4% of his time so occupied -- a savings of 3% per hour -- a useful savings. This technique gives the Coast Guard a reasonable idea of the magnitude of the time savings which can be expected. The Coast Guard can then decide, based on the dollar costs, whether to actually implement this equipment change.

c. Procedural Change

The effects of a procedural change can be similarly studied. Suppose for our example VTS in Figure 2-1, it is felt that the likelihood of a computer outage is high enough so watchstanders should have a backup system based on cards. Then the procedural steps are altered in Figure 2-1 by adding a block prior to step 5 and step 12 during which the watchstander fills out or makes a note on a card. Tables of durations are constructed for both of these blocks as shown in Table 2-4. The computer program is easily altered by the insertion of statements for the two new blocks and the addition of the two new data tables.

Computer simulations are conducted. Suppose they demonstrate that such a change in procedure adds approximately 6% to the time a watchstander is involved in demand activities. Most of this added time involves check-ins and contributes to a rise in the number and average duration of pilot radio calls delayed. Based on operational experience and these results, the Coast Guard can make an informed decision about the costs and benefits of changing these procedures.

d. Personnel Change

Actually a personnel change would be a change in requirements so that particular skills were developed through training, particular characteristics or backgrounds were sought, or particular physical abilities sought or excluded. Suppose, in our example, watchstanders were required, through either selection or training, to be able to key information into the computer at a specified rate, in contrast to the present situation of no minimum standards.

In Figure 2-1 only blocks 5 and 12 would be affected by such a requirement. Knowledge of the new rate would decrease the times shown in columns 5 and 12 in Table 2-2 to those shown in Table 2-5.

Computer simulations then indicate an average of 8 seconds decrease in the handling of a check-in call and 4 seconds for a check-out, increasing the time available for monitoring activities by 3% of an hour, every hour.

Based on this information about the magnitude of the gains they might expect and their experience in recruiting and training of VTS watchstanders, the Coast Guard must decide if the benefits warrant instituting such requirements.

Note that the VTS used throughout this section is an example based on a hypothetical VTS. The purpose of this section has been to illustrate the whole procedure involved in accomplishing the modeling task so that the program thus far can be put into perspective and so that the technique and some of its potential applications can be better understood. The rest of this chapter deals with the construction and verification of the actual models of VTS operations based on field data.

2.3 METHOD OF DEVELOPMENT

2.3.1 Data Requirements

Modeling of VTS operations at Houston-Galveston, New Orleans, Puget Sound and San Francisco require the following kinds of data:

1) The sequence of operations, i.e., the actual procedures.
2) The processing delay times of watchstanders and equipment at each procedural step.
3) The relative frequencies of the different operations at each branching point.
4) The time interval between incoming radio calls.

The following sub-sections describe how these data were gathered and processed for computer programming of the models.

2.3.2 Data Gathering

Details of specific procedures for data gathering at each of the four VTSs are described in References 1 through 4. However, the general procedure began with the available documentation from each center for use in construction of the block diagram. A team from TSC visited each site and began data gathering by observing watchstanders and discussing their actual procedures with them. Revisions to the block diagram were made based on the information thus obtained.

Data on processing delays and activity frequencies were gathered somewhat differently at each center. At the Houston-Galveston VTS, frequency counts were made of the various watchstander activities. Then separate measures of processing delays were made using a stopwatch. An observer dictated the start, stop and type of each watchstander activity into a tape recorder at both the New Orleans and Puget Sound VTSs. Later, these data were transcribed by a listener who recorded the type of activity and measured its duration from start to stop with stopwatch. These data were recorded using a datalogger device at San Francisco. Using this device an observer depresses buttons indicating the start and stop of various types of watchstander activities. These data are recorded into digital cassettes for later computer analysis. This analysis rapidly summarized both the types and durations of watchstander activity.

Radio communications between pilots and watchstanders were tape-recorded at all four sites for later transcription and detailed analysis.

2.3.3 Model Construction

The purpose of detailed communication analyses was to break the communications down into their component parts, determine the duration of each message, intermessage interval,* and intertransaction** interval and classify each message. The information obtained from this analysis is employed in the construction of both the block diagram and the supporting data base for the computer model.

An actual transaction (New Orleans VTS, Tape 3, transaction 9) is presented in Table 2-6 to illustrate the communications analysis procedure. The table shows the duration of each message and intermessage interval, the actual message, and a short, descriptive label categorizing each message. This transaction is classified as an advisory type of demand activity in the model because the major content and apparent purpose of the transaction are the same as for an advisory. This transaction lasts 36 seconds with a 252 second break or intertransaction interval until the next radio communication. Thus there is an interval of 288 seconds between the initiation of incoming radio transactions. The duration of these interinitiation intervals determines the rate at which the modeled watchstander must respond by performing demand activities.

Information on communications (similar to that shown in the above example) is then combined with data concerning watchstander procedures and interactions with equipment to formulate the final block diagram and supporting data base for the computer model. An illustration block diagram is presented in Figure 2-3. Note that the communications steps are combined with the watchstander's interactions with the equipment (in this case a computer) according to the procedure followed by the watchstander in handling advisories. Each step in the procedure and each line connecting these steps are numbered and the data for each is tabulated. So the 1 second required for the pilot to call-in listed in Table 2-6 is entered into the table for block 1. The following 2 second intermessage interval is entered into the table for block 2 and so on from Table 2-6 until block number 7. The data for this block are taken from timing measures of processing delays taken when the watchstander interacted with the equipment. In this manner the model of VTS operations is developed from the field data.

*An intermessage interval is the duration of the break between any two messages within a transaction. An intertransaction interval is the duration of the break between the end of one transaction and the beginning of the next.

**A transaction consists of a series of messages between a particular pilot and the VTS watchstander.

TABLE 2-6. TRANSACTION ILLUSTRATING THE DETAILED COMMUNICATIONS ANALYSIS

Duration (sec)	Message	Descriptive Label
Start of Transaction		
1	Vessel name, New Orleans Traffic	Pilot (P) calls in
2	--	Intermessage interval
2	Vessel name, this is New Orleans Traffic	Watchstander (WS) acknowledges
0	--	Intermessage interval
2	Vessel name is southbound	P gives position information, etc.
8	--	Intermessage interval
16	Vessel name, New Orleans Traffic, roger, sir. My display shows you should be meeting three reported southbound vessels up to your next checkpoint at Crescent Light: The first being the non-participant Vessel A; followed by Vessel B just underway from --- Island; followed by another non-participant Vessel C.	WS gives advisory
0	--	Intermessage interval
3	Roger, roger	P acknowledges and signs off
1	--	Intermessage interval
1	Traffic out	WS signs off
252	-----	Interval start of next transaction.

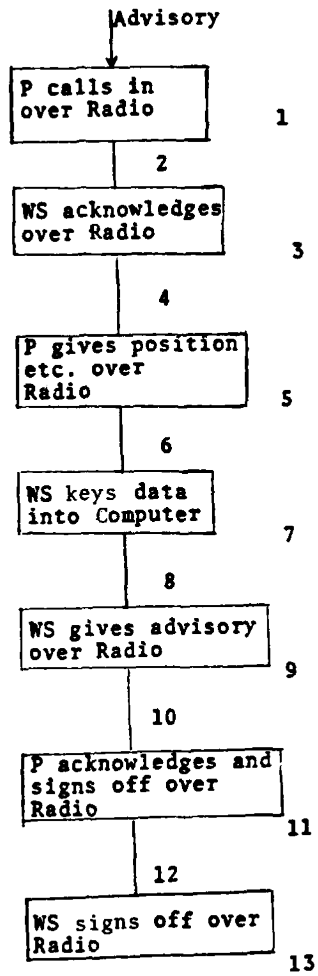

FIGURE 2-3. BLOCK DIAGRAM ILLUSTRATING METHOD OF COMBINING WATCHSTANDER COMMUNICATIONS AND EQUIPMENT ACTIVITIES

TABLE 2-7. SIZE CHARACTERISTICS OF VTS WATCHSTANDER SECTOR MODELS

VTS	HGI	HGII	HGIII	PS	SF	NOI	NOII	NOIII	TOTAL
DATA BASE									
No. of hours	5	5	5	6	10	4	4	4	43
No. of radio transactions*	205	123	194	245	200	68	59	70	1164
No. Vessel initiated	89	46	115	233	117	63	56	64	783
No. of WS radio messages and control actions	1768	1589	2162	3028	1576	1138	970	906	13,137
Total No. of data points	1857	1635	2277	3261	1693	1201	1026	970	13,920
BLOCK DIAGRAM									
No. of blocks	76	3	3	125	145	64	61	87	704
No. of branch points	6	5	5	10	16	17	13	19	91
No. of branches	16	12	12	26	31	36	30	37	200
COMPUTER PROGRAM									
No. of function tables	43	47	46	94	100	78	78	70	556
No. of program steps	214	215	223	397	362	342	308	372	2433
Total No. of lines	762	656	730	1294	957	805	733	815	6752

*Includes overlaps for HG.

2.4 RESULTS

This section presents results of several computer simulations of each sector. The purposes of these multiple simulations are to determine the magnitude of certain characteristics of each model and to verify each VTS computer model. The characteristics indicate the size of each model and the verification process indicates the accuracy of each model. The characteristics give an indication of the data base, the complexity, and the computer capacity and operational requirements of each sector model. Verification is performed as one check for errors in modeling. The computer simulation output, on the average, should agree with those data upon which the model is based. Significant deviations indicate either a clerical error in the data base or in the computer program or perhaps a faulty model. In each case, corrections would be required.

2.4.1 Model Characteristics

Eight sector models have been constructed: one for each of the three sectors at the Houston-Galveston VTS, one for each of the three sectors at New Orleans VTS, one for the Puget Sound VTS, and one for the San Francisco VTS. The data for the Houston-Galveston VTS models were gathered during the period September 19-21, 1977; for the Puget Sound VTS model, during the period Janaury 24-27, 1978; for the New Orleans VTS models, during the period April 10-14, 1978; and for the San Francisco VTS model, during the period July 10-13, 1978.

The magnitudes of certain characteristics of these models are summarized in Table 2-7. The characteristics are broken down into those descriptive of the Data Base, the Block Diagram, and the Program. The computer requirements and computer output are described in the text.

The size of the Data Base is described by a number of factors. The number of hours of field data incorporated into each model ranges from 4 hours for one sector at New Orleans to 10 hours for the San Francisco VTS model. The number of radio transactions which occurred during those hours is listed. This number includes overlaps from other sectors, particularly at Houston-Galveston. It also includes transactions which were too weak or garbled to be transcribed and those which were initiated by the watchstander. The number of vessel initiated radio transactions is listed separately because it is these transactions which demand activity from the watchstander. Each interval between initiation of these radio transactions (inter-initiation time) becomes a data point for the model. The number of radio transactions lies between 233 in six hours at Puget Sound to 46 in five hours at sector two of Houston-Galveston. The next descriptor in Table 2-7 accounts for all of the control actions and radio messages of the watchstander. Primary watchstander activities refer to those activities associated with interacting with the available equipment and communicating with pilots. This number ranges between 906 in four hours at sector three of New Orleans to 3,028 in six hours at Puget Sound. The total number of data points entered into the program is the sum of the number of vessel-initiated radio transactions and the number of watchstander control actions and radio messages. This number ranges from 970 in four hours of sector three at New Orleans to 3,261 in six hours at Puget Sound.

Each Block Diagram can be described in terms of the number of blocks, number of branching points and the number of branches coming from the branch points. Each block diagram consists of a number of blocks ranging from 61 for sector two of New Orleans to 145 for San Francisco. This number indicates the variety of different types of activities or procedural steps watchstanders go through to perform their job. Alternative procedures occur at various points in the block diagram. A higher quantity of branchpoints indicates an increasing complexity of operations modeled for the VTS. New Orleans sectors have the highest, 19, while Houston-Galveston sectors have the lowest, 5. Further indications of complexity come from the number of branches emanating from these branching points. A branching point might split into two branches, but it could split into many more. The number of branches goes from a high of 37 at New Orleans sector three to a low of 12 for sectors two and three at Houston-Galveston.

Descriptors of the Programs indicate the size of the computer model. An idea of this size can be conveyed in terms of the number of function tables, the number of program steps, and the total number of lines required to state the model in the GPSS computer language. Each block and each line connected between blocks has a distribution of delay times taken from the data base. For the computer program these data

are arranged into function tables. Some are duplicated throughout the model, so one function table may describe many blocks. The total number of function tables goes from 43 for sector one at Houston-Galveston to a high of 100 at San Francisco. The total number of program steps required to specify each model in GPSS ranges from 214 for sector one at Houston-Galveston to a high of 372 for sector three at New Orleans. The total number of lines includes those required to specify both the model and its supporting data base. This total goes from a high of 1,294 for Puget Sound to a low of 656 for sector two at Houston-Galveston.

The computer requires approximately 27K of 32 bit words of core memory space to simulate each sector model. Each simulated hour takes about 15 seconds of computer time to compile and up to 23 seconds to execute. The program and computer specifications are based on operating the GPSS V.10(60)* on TSC's DEC-10 computer. Some additional Fortran IV statements were written to select certain GPSS output for listing in a usable output format (see Table 2-3).

2.4.2 Verification

The verification method involved comparison of the results of multiple simulations with the field data on the basis of several important parameters. The use of multiple simulations insures statistical reliability, i.e., the results of one hour of computer simulation could be spuriously high or low but an average of several simulated hours will be stable. Verification is accomplished by comparing simulation and field data on the basis of parameters describing radio communications; the durations of watchstander responses to the following demand activities; check-ins, advisories and updates, check-outs, and others; and proportion of time available for monitoring.

In the paragraphs to follow, for each VTS, several simulated hours are compared with the average of several hours of field data. A VTS computer model is considered verified if its simulation data are equivalent to the field data according to the established criterion (see Section 2.2.7, Verification).

It is important to note that prior to this report such comparisons were made as a part of the development of this modeling technique without a criterion. Previous models were developed for only one sector at each VTS, based on only two or three hours of field data, and compared to only one hour of simulation results. The present verification comparisons are based on complete models; that is, all sectors are modeled, based on virtually all of the available field data including a full and detailed re-analysis of the radio communications data, and compared with a substantial number of computer simulation hours.

Comparisons between several computer simulation hours and several hours of field data are presented in Figure 2-4 through 2-7 for a number of parameters for each VTS. Figure 2-4 compares seven computer simulation hours with six hours of field data for verification of the Puget Sound VTS computer model. Figure 2-5 compares seven computer simulation hours with ten hours of field data for the San Francisco VTS computer model. These comparisons are presented in Figure 2-6 for the New Orleans VTS computer model with twelve hours simulated and twelve hours field data; and in Figure 2-7 for the Houston-Galveston VTS computer model with twenty-one hours simulated and fifteen hours field data.

The New Orleans and Houston-Galveston VTSs have three sectors each. For these comparisons both the field data and the simulation results have been combined.

In the left portion of each figure, radio communications activity is compared in terms of the average number of mariner-initiated radio transactions per hour and the range, or minimum and maximum number. For each VTS, several radio transaction levels falling within the range of the field data were selected for input to the simulation. As shown, their averages are virtually identical to those of the field data for all four VTSs. Consequently, in terms of this parameter, radio transactions per hour, the major input to both the computer model simulation and the actual VTS is the same.

VTS response to these mariner-initiated radio transactions is described in the central portion of each figure in terms of the average duration (plus or minus one standard deviation) required for completion of each of the four categories of demand

*M. David Martin, Department of Computer Science, University of Western Toronto, London, Ontario, Canada, author of this GPSS version.

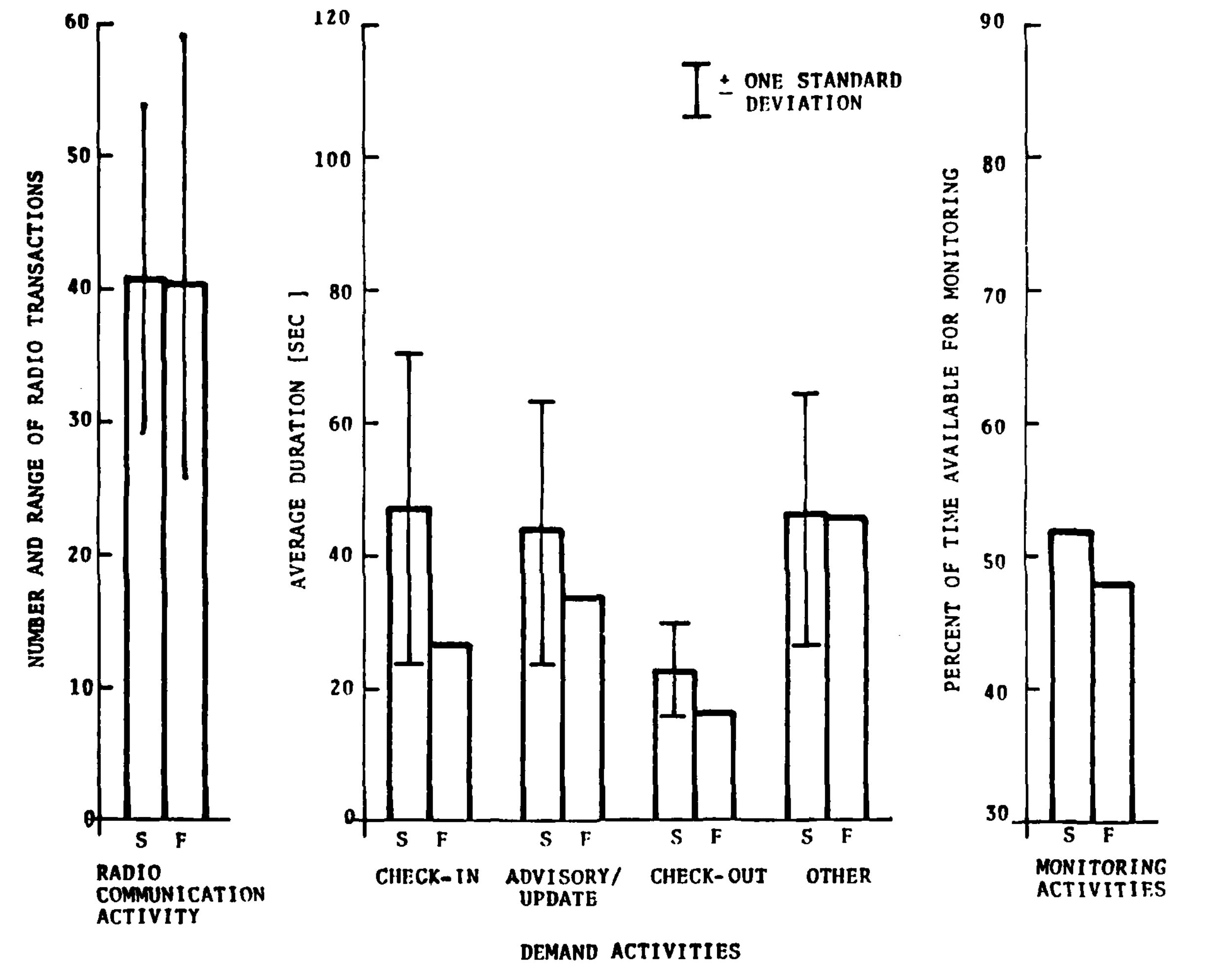

FIGURE 2-4. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF PUGET SOUND VTS COMPUTER MODEL

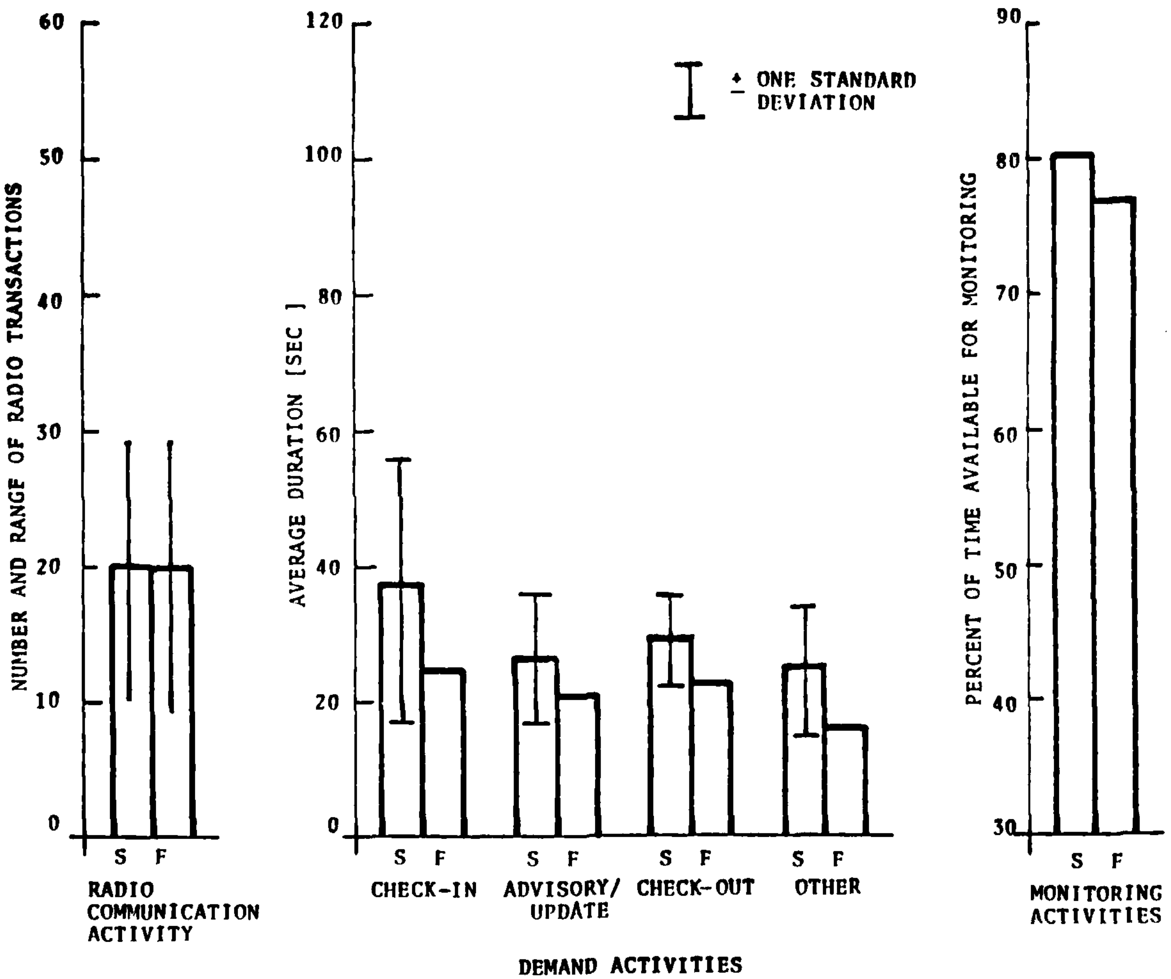

FIGURE 2-5. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF SAN FRANCISCO VTS COMPUTER MODEL

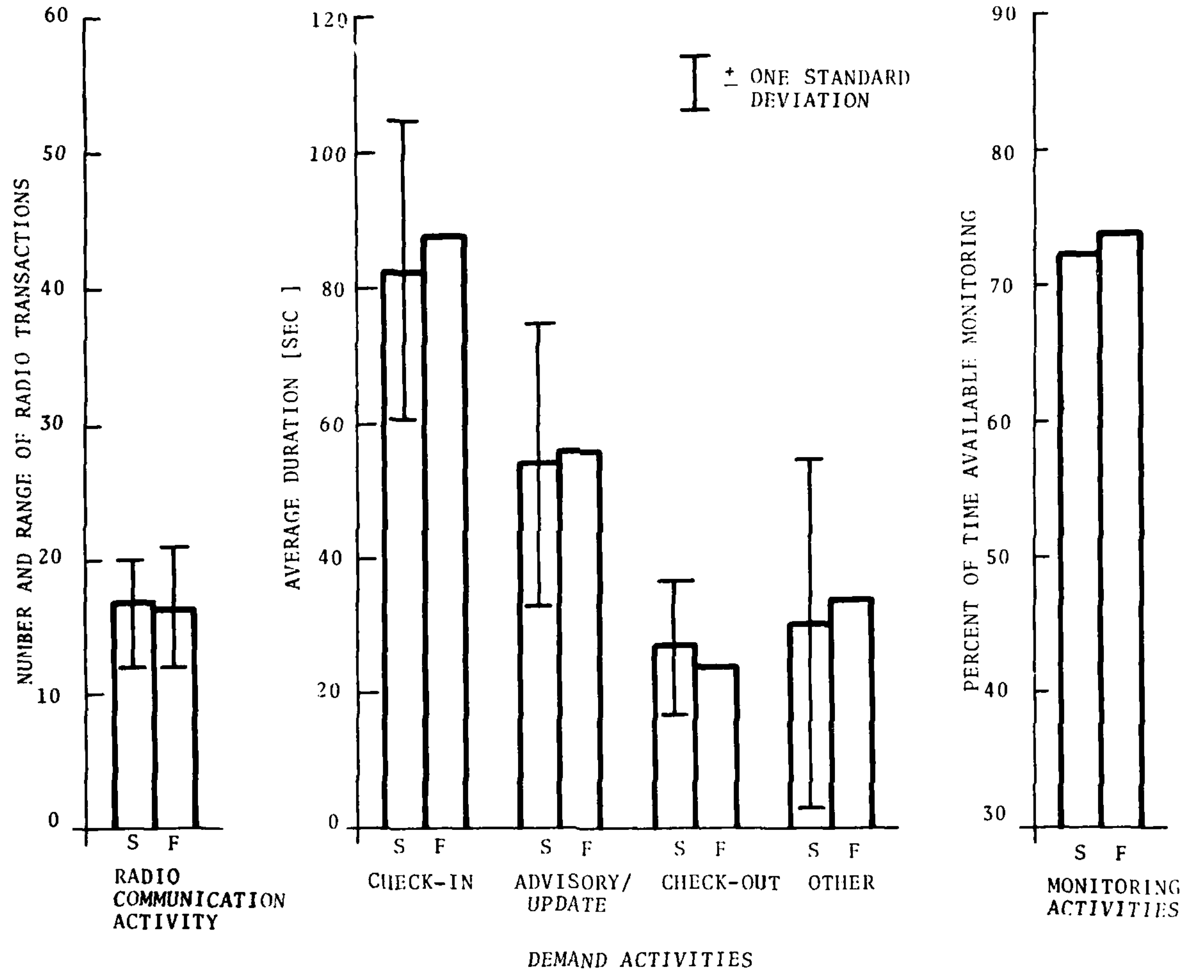

FIGURE 2-6. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF NEW ORLEANS VTS COMPUTER MODEL

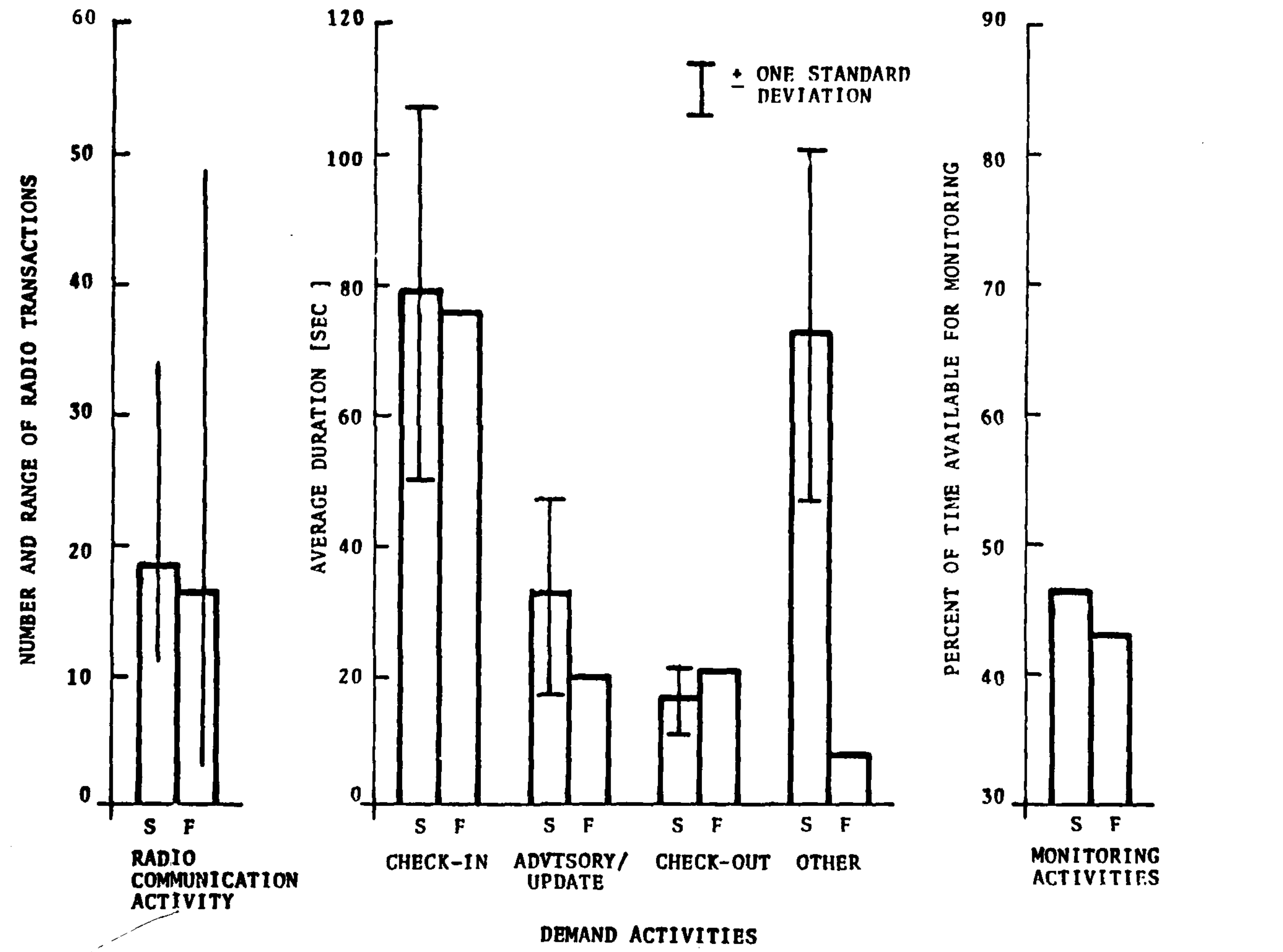

FIGURE 2-7. COMPARISON OF COMPUTER SIMULATION AND FIELD DATA FOR VERIFICATION OF HOUSTON-GALVESTON VTS COMPUTER MODEL

activities -- check in, advisory or update, check out or other. As shown, the distribution of simulated durations compares, within the criterion, with the average of the field data for all of the demand activities for the Puget Sound, San Francisco and New Orleans VTS models and all but "other" for the Houston-Galveston VTS model.

A comparison of the percent of time available to the watchstander for monitoring after completion of demand activities is presented in the right portion of each figure. The average proportion of several (simulated) hours comes within four percent of the average of all of the field data taken at each VTS.

In summary, verification comparisons between all of the available field data (including a detailed re-analysis of the radio communications data) and a substantial number of computer simulation hours of completed models were made on the basis of several important parameters for each of the four VTSs.

For each VTS, descriptions of vessel initiated radio communication activity were virtually identical for both the model simulation and the actual VTS. The distribution of simulated durations is equivalent, within the criterion employed, to that of the field data for fifteen of the sixteen points of comparison among the demand activities. The mean proportion of watchstander time available for monitoring for an average of at least seven simulation hours comes within four percent of the mean of all the field data taken at each VTS.

The only discrepant point of comparison is the "other" demand activity at Houston-Galveston. The magnitude of the simulation results exceed those from the field indicating the possibility of attributing extra steps to watchstander activity. Slight corrections to the computer model usually remove such discrepancies. However, in the case of the "other" demand activity at Houston-Galveston, the 8 seconds field average for this activity appears inordinately low. The "other" demand activities average 16 seconds at San Franciso, 34 seconds at New Orleans and 46 seconds at Puget Sound. However, the simulation results of 73 seconds seems inordinately high also. Both further field data and re-examination of the computer model are indicated here.

In conclusion, the New Orleans, San Francisco, and Puget Sound VTS computer models are verified. The Houston-Galveston VTS computer model is also verified with slight corrections indicated for "other" demand activities.

2.5 DISCUSSION AND CONCLUSIONS

The modeling process consists of four states; development, verification, validation, and applications. The development and verification of computer models simulating operations at four VTSs is complete. The computer models are based on all of the available data collected during typical operations at each sector of each VTS; San Francisco, Puget Sound, Houston-Galveston, and New Orleans. This data base consists of a detailed analysis of communications activities as well as time and frequency measures of other watchstander activities. These completed models encompass some 14,000 data points requiring 2,400 lines of GPSS program steps to describe. Each sector model requires about 15 seconds to compile and another 5 seconds per simulated hour. Some 27K of 32 bit words of computer core memory are required for simulation of each sector model in GPSS on TSC's DEC-10 computer.

Each VTS computer model was verified through comparison of the results of a substantial number of simulated hours with the field data recorded over several hours at each VTS. Parameters describing radio communications, demand, and monitoring activities compared within the bounds of a pre-set criterion. This verification demonstrates that there are no detectable errors in either model construction or computer entry.

Computer models for the San Francisco, Puget Sound, Houston-Galveston and New Orleans VTSs are complete and verified. Each is sufficiently complex to be usefully descriptive of VTS operations and watchstander performance, yet it is of a size readily simulated on a computer and easily changed to explore the effects of candidate changes in VTS operations.

Validation of this technique is now necessary. It is recommended that a model be prepared predicting the effects of using a proposed new input/output terminal at the Houston-Galveston VTS and that the model be run to generate predicted operating functions. If the technique is valid, the predictions should agree with operating functions derived from data gathered on-site after the terminal has been put into operation.

3. STUDY OF EFFECTS OF WORKLOAD

The initial models of watchstander activity developed in FY78 were based on measurements and observations made during routine operations. It is well understood that watchstander performance changes considerably when the system is stressed by such events as accidents or incidents within the system, special events producing traffic congestion, failure of aids to navigation or traffic surveillance equipment, or severe weather conditions such as fog or storms. Moreover, a major criterion of system effectiveness is the manner in which the VTS functions in these stress situations. Thus it is imperative that models used to evaluate the system reflect activities during increased workloads as well as during routine operations.

3.1 SURVEY OF APPROACHES

Since it was realized that only in rare circumstances would it be possible to collect data at a VTS on an occasion of system stress and high workload, a survey was designed to evaluate the feasibility of several methods or approaches for collecting alternative data on workload effects.

3.1.1 Procedures

Personnel at each of the four VTSs previously studied were interviewed in depth to obtain information relating to problems of increased workload. Officers and enlisted men with at least one year's experience as a watchstander were asked to describe procedures in responding to emergencies and system overloading. They were also asked to describe actual experiences during specific incidents of system stress.

During the interview with the commanding officer of each of the centers three additional topics related to increased watchstander workload were discussed:

1) Whether or not there were any scheduled events which could be anticipated and would be expected to increase workload or create unusual or extreme working conditions (e.g., regattas or construction on shipping channel).
2) Post-emergency or post-incident critiques which could be attended by a TSC observer or recorded for later analysis.
3) The feasibility of using traffic simulations to examine this workload problem experimentally.

Each of these approaches would aid in understanding the operation of a VTS under conditions of system stress.

3.1.2 Results

Data gathered from interviews with key personnel led to the following general conclusions:

1) Available data from watchstander performance under stress are sparse and unquantified.
2) No stress situations could be anticipated that would permit the scheduling of data collection during the events.
3) There are no formal post-incident critiques held at any of the centers.
4) The active computer-based systems are not programmed for off-line simulations of traffic.
5) VTS commanding officers are firmly opposed to simulation studies that would interfere with operating watchstanders.

Based on this information it was decided that an experiment simulating operations on a non-interference basis at one of the centers seemed the most promising way to increase understanding of VTS operations under nonroutine situations.

3.1.3 Justification for Experimentation

A simulation experiment permits the introduction and the control of conditions affecting system performance that cannot be handled in field studies of an operating system. Simulation of VTS operations has three potential benefits:

1) The effect of extreme workload conditions can be tested. The GPSS models of VTS operation are based on data obtained under routine operating conditions. Simulating extreme workload would yield data on watchstander performance that would either verify predictions made from the GPSS models or provide guidance for modifying the models.

2) The effect of changes in equipment and procedures can be simulated. The capability is particularly valuable for testing advanced concepts as a guide for the design of new and improved systems.

3) These effects can also be used to anticipate and allow for problems associated with transition from one system configuration to another.

After examination of the surveys conducted at the four VTSs, it was decided that the Puget Sound VTS was most suited to the needs of this study for the following reasons:

1) Simulation of current (manual) operations was feasible without interference with operations. The plotting table was scheduled to be replaced by vertical magnetic plotting boards that could be easily simulated.

2) PSVTS faced a series of transitions (sectorization, new board, additional radar, and a second generation computer) that would justify a series of simulation studies as an aid to planning these transitions. A workload study which yielded data relative to Puget Sound operations could serve as the first such study.

3) The Commanding Officer would welcome further studies at PSVTS.

3.2 PURPOSE OF EXPERIMENT

The purpose of the experiment was to collect data on typical watchstander job performance under simulated conditions of high workloads. This information was needed to guide formulation of training and operating procedures and to extend the GPSS model of watchstander performance to the more extreme workload conditions.

3.3 DETAILS OF EXPERIMENT

3.3.1 Subjects

Ten watchstanders served as subjects in the experiment with an experience range from a maximum of 13 years combined in the Coast Guard and Navy with over five years of VTS duties to a minimum of 15 months in the Coast Guard and only 5 months of VTS duty. Their grades ranged from E3 to E7, and most had had previous sea duty.

3.3.2 Equipment

The equipment for the simulation consisted of three basic components: a vertical plotting board with vessel models, a communications console, and a script for the vessel initiated transactions (VITs).

The plotting board was a 4 ft x 6 ft metallic board with a translucent map overlay of Puget Sound between Point Vashon and Double Bluff, at a scale of 1:80,000. This area was chosen for the simulated traffic area because it could most realistically support an increased traffic load. The area included Elliott Bay (Seattle), north and south bound traffic lanes, and areas with traffic crossing the lanes enroute to or from Bremerton, Bangor, and Everett. Magnetic data tiles and the vessel symbols, identical to those used in operations on the current vertical plotting boards, were available for use in plotting vessel transits through the system.

The plotter/communicator position was constructed to resemble an actual work station with a communications console, a card punch and storage rack, and appropriate work space (See Figure 3-1).

Communication equipment included a head set and a console for the subject and for the experimenter. The subject spoke with the simulated vessels simply by talking into the microphone. The experimenter had a tape recording of all scheduled VITs which he would transmit at given intervals. The experimenter also had the capability of speaking directly with the subject via a microphone. The experimenter acting as a vessel master or pilot, was thus able to respond to specific questions and statements made by the subject.

3.3.3 Data Recording

There were three basic data records kept for each of the ten exercises: a voice recording of all communications, a frequency/duration count of the major activities performed by the subject, and a handwritten log of unscheduled events, such as problems the subject might be having or the subject's indicating that he would ask for assistance if this were an actual operational situation. Frequency and duration of activities were recorded on magnetic tape through a keyboard device; depression of a key coded for an activity created a record of which key was depressed and the time at which it was depressed.

Blood pressure and heart rate were measured immediately before and after the excercise in an attempt to evaluate the presence of physiological stress attributable to the simulation. Urine samples were collected for most subjects.

After the simulation each subject was interviewed to obtain his explanation for various actions which he made during the hour and to get his general impressions on the exercise.

3.3.4 Preliminary Procedure

The basic purpose of this study had been explained to all of the potential subjects in the days prior to the commencement of the simulation. They all knew that some of them were going to participate in a communications simulation, similar to one used by this center in their training program. All subjects of the study willingly participated.

After being ushered into the room, each subject was given a pre-simulation interview; his blood pressure and heart rate were recorded, and a urine specimen was taken. Then he was shown the simulated watchstander station while the experimenter explained the situation and what was expected of him. The elements of the situation were all familiar to the subject. The board, shown in Figure 3-2, contained the models for 16 vessels in their updated positions. There were eight vessels that had already given their pre-departure call awaiting entry and eight vessels currently transiting the system. Correspondingly, there were 16 vessel status cards in the active file rack.

Each subject was told that he was relieving another watchstander who had been working the station. The subject was to assume that everything was correct as he took over. All vessels on the board were checked in, each vessel knew about each other vessel, all the cards in the file were properly annotated, etc. In other words there was nothing required of the watchstander at the start of his watch. However, he was given one item of information that was not apparent on the board; one vessel, the Sea Wench, enroute to Bremerton, had apparently lost her radio and had not been heard from at her last check point. The subject was not asked to do anything in particular about this; he was simply notified of the situation. When the subject had had a few minutes to familiarize himself with the board, vessels, and cards and adjusted the equipment to suit himself, he indicated that he was ready to begin. At this point the hour simulation began. Clocks and tapes were started, and the first VIT came about 15 to 20 seconds later.

3.3.5 The Simulation

The first ten minutes of the simulation progressed at a speed more or less determined by the subject. The experimenter would proceed through the VITs at a pace

At the left hand is an experimenter who is recording activities; in the center is an experimenter who is keeping the log, and to the right hand is a subject. The communicating experimenter is behind a screen in back of the viewer.

FIGURE 3-1. THE EXPERIMENTAL POSITION

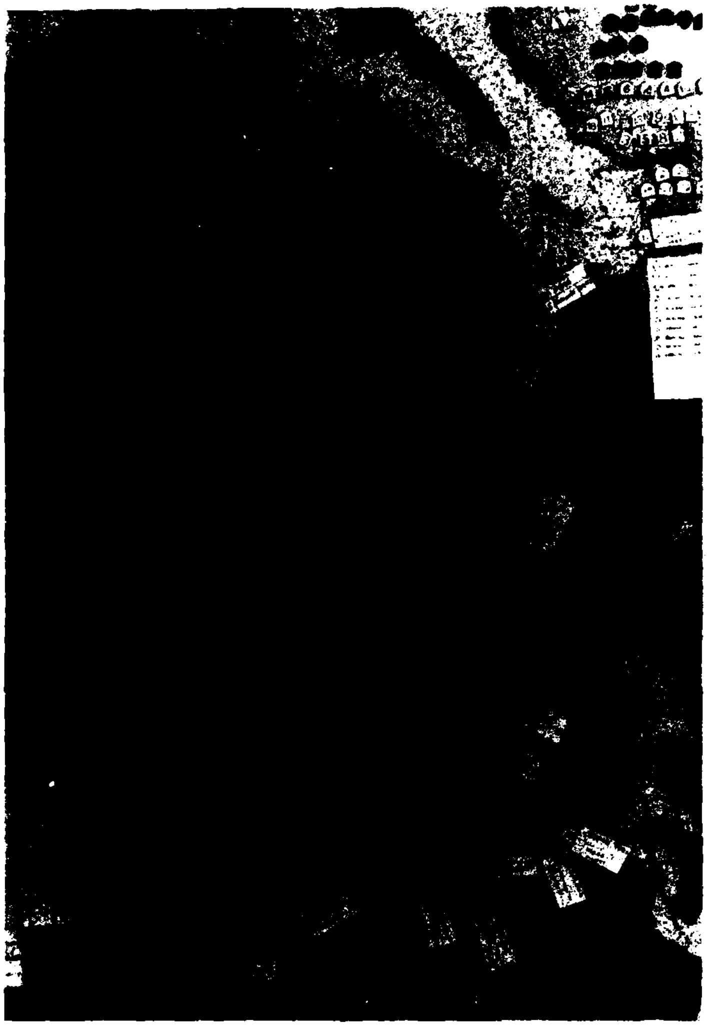

FIGURE 3-2. PLOTTING BOARD AT START OF SIMULATION

which would not rush the subject. After each VIT, the experimenter would wait at least until the subject had finished all work associated with that vessel before initiating the next VIT. This 10-minute introductory period also allowed time for the subject to get accustomed to the simulation.

During the second 10 minutes, VITs were presented in closer succession to ease the subject into what was soon to be an extremely fast succession of communications with little or no time for other necessary activities. At the end of 20 minutes each subject should have been at approximately the same VIT in the simulation.

During the second 20 minutes, the VITs came much more quickly, allowing little time for anything but responding to the calls. This high workload level continued into the last 20 minutes. For those subjects whose plotting and communicating kept pace, or nearly kept pace, with the VITs there was some relaxation in the frequency of the VITs during the last 5 minutes. The entire period of simulated radio transactions was designed to put some pressure on even the most efficient watchstander and to create severe problems for the least efficient.

During the course of the hour four incidents were presented to the subject. Near the start and again near the end of the hour, a vessel made a routine call but complained about an inability to get through to the center.

In the first case, the complaint was not justifiable but in the latter it was perhaps justified. Approximately 10 minutes into the exercise, a vessel called the center to report a deadhead (log) floating in Possession Sound. The last incident occurred about 2/3 of the way through the experiment, when one vessel called in to report a fishing vessel foundering.

Since subjects were told to act and respond in the simulation just as they would in actual operations, there were no specific responses being sought to these incidents. Whatever reaction was made by each subject was treated as adequate. After the simulation, in the debriefing, subjects' responses to these incidents were discussed.

3.3.6 Post-Simulation Procedure

At the end of 60 minutes, the experiment was stopped, the subject's blood pressure and heart rate were recorded, and a post-simulation interview was conducted. (Most subjects were asked to provide an additional urine specimen immediately after the experiment.)

3.4 RESULTS OF EXPERIMENT

3.4.1 Treatment of Data

The various kinds of data collected during the experiment are summarized in Table 3-1. Equipment malfunction prevented the recording of activities data for Subject 5, and collection of urine samples was incomplete for several reasons (subject unable to produce a sample, subject on medication, inadequate time available,etc.). Otherwise, all data were collected on all subjects.

The voice tapes were analyzed by listeners, who recorded the nature and duration of each voice message. A computer program was prepared to analyze the activity tapes, yielding the sequence of activities and the mean duration and standard deviation of duration for each activity code recorded. The communications and activities results were combined to produce a minute-by-minute account of how each subject's time was spent throughout his hour of simulated duty. Notes from the manual log and interviews were used to help resolve problems of interpretation. From these summaries, the percentage of time spent in communicating and in plotting were determined.

At the end of each run, the subject's plot was photographed. Although the number of vessels in the systems varied from subject to subject, six vessels were in the system with constant speed throughout the exercise; thus their correct positions at the end of the experiment were known. The distance of each of these vessels from its correct position was measured on each subject's plot photograph, and the average of these errors (in miles) was used as an index of final plot accuracy.

TABLE 3-1. DATA COLLECTED IN WORKLOAD EXPERIMENT

TYPE OF DATA	SUBJECT									
	1	2	3	4	5	6	7	8	9	10
Voice Tape	X*	X	X	X	X	X	X	X	X	X
Activities Tape	X	X	X	X		X	X	X	X	X
Manual Log Notes	X	X	X	X	X	X	X	X	X	X
Post - Experiments Plot Photo	X	X	X	X	X	X	X	X	X	X
Pulse Rate - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X
Urine Sample - Pre-Experiment		X	X		X	X	X	X	X	
Post-Experiment		X	X		X	X	X	X	X	
Stress Rating - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X
Interview - Pre-Experiment	X	X	X	X	X	X	X	X	X	X
Post-Experiment	X	X	X	X	X	X	X	X	X	X

*Incomplete data.

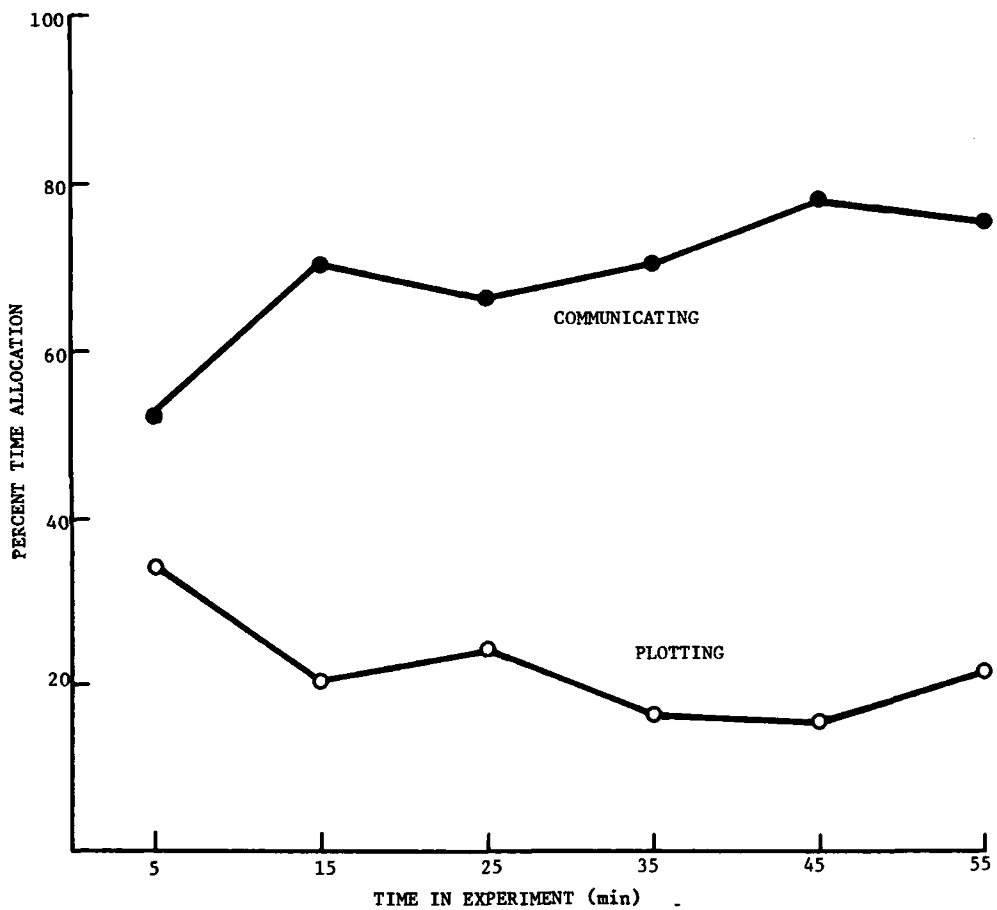

FIGURE 3-3. AVERAGE ALLOCATION OF TIME

Urine specimens were analyzed by specialists under contract. The results were expressed as rate of secretion of adrenalin in nanograms per minute. Selected portions of communications tapes were analyzed for evidence of voice stress by a specialist under contract. Messages of innocuous content (e.g., "Seattle Traffic") were selected, six from the early part of the experiment (low stress situation) and six later (high stress). Tapes were sampled for two subjects, one who clearly was stressed, as evidenced by change in heart rate, blood pressure and adrenalin excretion as well as observed overt behavior, and another whose indications suggested low stress. All voice samples were rated as showing stress on a scale of 0 to 5.

3.4.2 General Allocation of Time

The driving force in the experiment was incoming communications, and as their frequency increased, either plotting functions were delayed or postponed, or strategies to control the time spent in communicating were adopted to permit keeping up the plot. The tradeoff between time allocated to communicating and time allocated to plotting is thus a focus of interest.

The percentage of time spent in communicating was determined for eight of the subjects* for each ten-minute interval during the experiment. Likewise, the percentage of time given to plotting functions (marking cards, marking tiles, and placing and moving tiles on the board) was determined. When plotting functions were performed while communicating, the time so spent was scored as communicating time. Average allocations of time for the eight subjects for each ten-minute interval are shown in Figure 3-3.

On the average, the group allocated 52 percent of their time to communications during the first 10 minutes, when the traffic load was light. An earlier study of routine operations at PSVTS (Ref. 2) showed the primary communicator spending 40 percent of his time communicating. Considering that the experimental situation included a ship without a radio and floating logs in the system, the first ten minutes of the simulation was probably representative of the watchstanders' regular performance. As the traffic load increased, communicating time also generally increased through the next 40 minutes, with a slight decrease in the last 10 minutes, when many subjects has reached a point of diminished traffic demand. A slight reversal of this trend in the third 10-minute period reflects the influence of three subjects who apparently cut back on communicating to catch up with plotting tasks.

The curve for time spent in plotting functions is essentially the mirror image of the communicating trends, clearly demonstrating the tradeoff between communicating and plotting and showing that, for the group as a whole, the plotting function suffered as traffic demands increased. Beyond this generalization, however, it is necessary to inspect the characteristic behavior of individual watchstanders and to compare this with their effectiveness before conclusions can be drawn about coping with heavy traffic.

3.4.3 Performance Effectiveness Measures

3.4.3.1 Performance Scores - For each subject, the experiment differed, since each subject's responses and strategies paced his run. Also, since the experiment was exploratory, there was no predefined criterion of "good" or "poor" performance. After considerable study of alternative scoring methods, two measures were judged to be related to effective coping with the heavy traffic situation. The programmed inputs (vessel-initiated transactions, or VITs) were 52 in number; so the number of the last VIT in each subject's run was selected as a measure of ability to keep up with communication demands. Keeping up, however, may not be desirable if it is accomplished at the expense of accuracy in the plot and advisories. Therefore the average error in the final positions of the six "constant" vessels (see Section 3.4.1) was adopted as an error index. Dividing the final VIT number by the average error yielded a performance index (PI) exponentially weighted for accuracy, reflecting the importance attributed to providing accurate advisories. These performance measures are shown for the ten subjects in Table 3-2.

*Equipment problems resulted in inadequate data for this analysis for subjects 1 and 5.

TABLE 3-2. MEASURES OF PERFORMANCE EFFECTIVENESS

MEASURE OF PERFORMANCE	SUBJECT									
	GOOD		AVERAGE						SP	POOR
	2	3	9	4	1	10	5	8	7	6
SCORE										
Last vessel-initiated transaction (VIT)	50	44	52	49	52	52	43	52	31	45
Mean error score (in miles)	1.3	1.2	1.7	1.6	1.8	1.9	1.6	2.0	1.2	3.8
Performance index (PI)	38.5	36.7	30.6	30.6	28.9	27.4	26.9	26.0	25.8	11.8
SEA WENCH RADIO PROBLEM										
Attempted to call Sea Wench	X	X	X	X		X		X	X	
Notified Sea Witch									X	
Notified two other vessels	X	X								X
Notified one other vessel					X	X				
DEADHEAD (FLOATING LOG)										
Notified watch officer	X	X	X	X	X	X	X	X	X	X
Notified other vessels	X	X	X	X		X	X		X	X
COMMUNICATIONS DELAY										
Apologized		X			X	X	X	X	X	X
FOUNDERING VESSEL										
Notified watch officer	X	X	X	X	X	X	X	X	X	X
Requested additional information	X	X	X			X	X	X	X	X
Checked for vessels in vicinity					X		X			

SP = Special

The PIs in Table 3-2 can be grouped as follows: PI above 35, good* performance; PI between 25 and 35, average performance, and PI below 25, poor performance. We thus consider Subjects 2 and 3 as the best performers, Subjects 1, 4, 5, 7, 8, 9 and 10 as average, and Subject 6 as poor.

3.4.3.2 Critical Incidents - An analysis of each subject's reaction to the critical or unusual incidents in the simulation provides additional information on watchstander activity under workload stress. In interpreting their reactions, it must be remembered that the artificiality of the created incidents may have caused somewhat arbitrary reactions. That is, some subjects may not have accepted the importance or critical nature of these incidents enough to give responses equivalent to what would occur under operational conditions. These reactions are summarized in Table 3-2.

3.4.3.3 Loss of Radio Contact - As soon as the simulation started, there was an opportunity for the subjects to attempt to contact the Sea Wench, a vessel who had lost radio transmission capabilities. Although no instructions to do so were given, 7 of the 10 subjects did attempt to contact the Sea Wench.

Since the Sea Wench could not be raised on the radio, the question became one of whether the subjects would notify approaching vessels of the situation. During the course of the hour, three different vessels called the center (one vessel called twice) with a precall or an underway call from either Bremerton or Port Orchard. Each of these vessels would be meeting the Sea Wench enroute and, therefore, should have been told of the radio difficulty. The first VIT was from the Sea Witch getting underway from Port Orchard to Seattle and timed to meet the Sea Wench at the bend in Rich Passage. Only one subject told the Sea Witch about the radio problem with the Sea Wench.** The other two vessels who would be meeting the Sea Wench initiated VITs a total of 22 times to the 10 subjects. Of these 22 opportunities to inform the vessels of the Sea Wench's radio malfunction, a subject relayed this information only 6 times. In other words, there were 13 occasions (out of a possible 22) where a vessel was never told of the Sea Wênch's problem.

3.4.3.4 Deadhead in Water - The next incident occurred when a vessel called in to the center reporting a deadhead (floating log) in the Possession Sound about half way between Possession Point and Elliot Point. In every case the subject reported the incident to the "watch officer" and eight subjects relayed the information to concerned vessels when the occasion arose. The two who did not report it were severely pressured and behind in their plot.

3.4.3.5 Communications Delay - Twice during the simulation, once in the first 20 minutes and again in the last 20 minutes, a pilot called the center and complained of an inability to get through on the radio. Seven subjects apologized for the inconvenience and two of the seven added that they had not heard any previous calls by that vessel. Three subjects did not apologize but carried on with the usual manner of communicating. In each case the subjects were courteous and professional in their demeanor.

3.4.3.6 Foundering Pleasure Craft - The only event which called for some action of the subjects was the notification of a pleasure craft foundering in the sound. In actual cases like this, it is the watchstander's duty only to inform the watch officer of the incident and the watch officer would take appropriate action; usually notifying SAR. In the simulation nine subjects notified the experimenter acting as watch officer, and one subject did not. Eight subjects asked for further description of the incident (color and description of the vessel, number of people on board, estimation of danger of sinking, etc.), and two recorded only the information provided by the calling vessel (number of people on board, estimation of danger of sinking, etc.). Two subjects, in addition to notifying the watch officer, attempted to contact other vessels in the vicinity of the sinking boat and request aid from them.

*The PI will be used as an index of good or poor performance in subsequent discussion; it is important to keep in mind that it is an arbitrary index based on what the authors considered desirable performance.

**It may be unfair to criticize the subjects for not mentioning the radio problem to the Sea Witch since, in their initial instructions, they were told that each vessel on the board (including the Sea Witch) knew about every other vessel and there was no need to update anyone. Most of the subjects may have assumed that this meant the Sea Witch knew of the Sea Wench's problem and that no further notification was warranted.

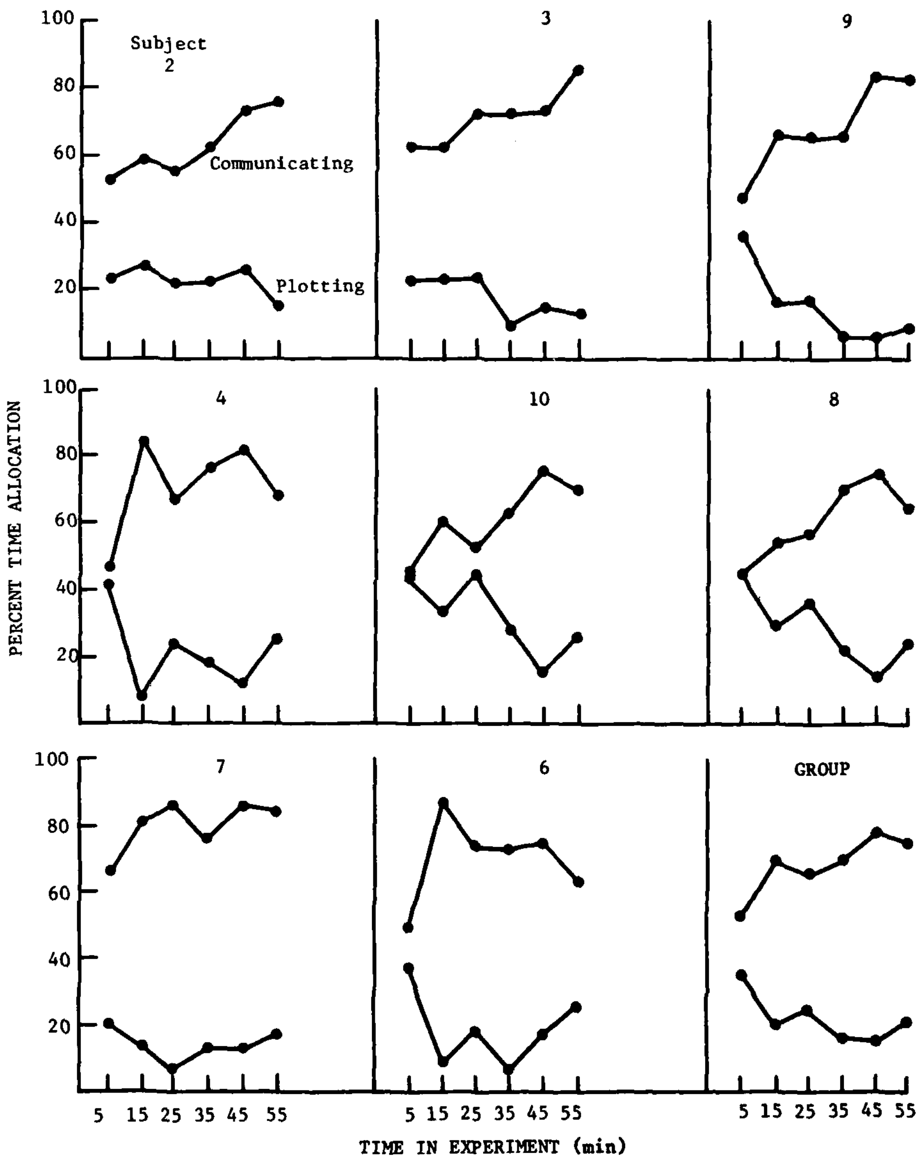

FIGURE 3-4. INDIVIDUAL TIME ALLOCATIONS

It was noted by the experimenter that, although the next VIT immediately after the sinking vessel call was an underway call by a Coast Guard cutter, none of the subjects asked the cutter to offer assistance. When queried about this in the debriefing, they responded that they are not authorized to request anything from a Coast Guard vessel. All requests must go through proper channels.

3.4.3.7 Summary - In summary, those subject who were under the most pressure tended to leave out (forget?) information that should be passed to concerned vessels (e.g., information concerning the Sea Wench losing its radio), but all subjects remained courteous and professional in dealing with upset pilots and all but one handled the most extreme situation (the foundering boat) in at least a minimally acceptable manner.

3.4.4 Individual Time Allocations

In Figure 3-4, the individual time allocations are shown for the eight subjects (arranged in descending order of PI) who were combined in Figure 3-3, which is repeated under the heading "Group". It is apparent that the curves for Subjects 9, 4, 10 and 8, are similar and resemble the group curves. The curves for Subjects 2 and 3, the good performers, resemble each other, and the curves for Subject 6, the poor performer, and Subject 7, a special case, are unique. From these curves and the performance measures, it is possible to generalize that the average performers managed to avoid loss of plotting time during the early period of traffic buildup by controlling the amount of time spent communicating. The poor performer, Subject 6, and Subject 7 both talked a lot and plotted relatively little, yet Subject 7 maintained accuracy at the expense of falling behind and working from a plot that had not been updated in the last 30 minutes by the end of the experiment.

3.4.5 General Strategies

As communication demands began to interfere with plotting functions, the subjects adopted a variety of strategies to effect a tradeoff between communicating and plotting. Some techniques were aimed at reducing communicating time, others at reducing plotting time. Some people neglected plotting or asked for help in plotting. Other techniques involved temporary tradeoffs.

3.4.5.1 Reducing Communicating Time - Communicating time was reduced by shortening messages, or decreasing the number of messages. Messages were shortened by omitting superfluous words (such as repeated call signs) or information judged unessential and by issuing advisories only on traffic in a vessel's immediate vicinity. Messages omitted included advisories when there was no significant traffic, and advisories on meetings in traffic lanes. Sometimes the watchstander simply neglected to give any advisories while plotting. The number of messages was reduced further by issuing group advisories to several vessels at one time and minimizing center (subject)-initiated transmissions (CITs)--that is, advising only on vessel-initiated transactions.

3.4.5.2 Reducing Plotting Time - Plotting time was reduced by adopting efficient procedures ("streamlining"), omitting plots of some traffic, neglecting plotting, or asking for help in plotting. Techniques for "streamlining" included marking and moving cards and tiles while talking, using abbreviations on cards, grouping card marking and tile marking activities to minimize changing pens, or taping two pens back-to-back. One watchstander omitted the plotting of tugs without tows. There were several cases where updating the plotting board (regularly required every 15 minutes) was completely neglected.

In real-life operations, a heavy traffic condition is first met with assistance in plotting from another watchstander (the external communicator or the radar plotter). The subjects were asked to report to one of the experimenters at any time that they would normally request assistance, even though such assistance was not provided in the experiment. Six subjects either requested help or reported after the experiment that they would have requested help.

3.4.5.3 Temporary Tradeoffs - Time was bought both in communicating and plotting by assigning priorities to demands and attending only to urgent business, postponing low priority tasks until such time as the workload might become lighter. Finally, the most frequently used practice to gain time was to put incoming calls on "hold"--that is, to ask the caller to wait until the watchstander called back. Eight subjects employed "hold" from 4 to 19 times.

3.4.5.4 Summary of Strategies - Table 3-3 summarizes the strategies observed or reported during the experiment. Subjects are arranged in the table from left to right in descending order of PI; thus any clustering of entries is roughly indicative of the effectiveness of the strategy.

3.4.6 Individual Strategies

To appreciate better the variety of strategies adopted to cope with the traffic load, and to interpret the impact of these strategies on effectiveness, it is necessary to follow individual subjects' progress through the experiment in more detail. As an aid to this analysis, additional measures of communicating characteristics are summarized in Table 3-4.

3.4.6.1 Good Performers - Subject 2, the best performer according to the PI managed to keep up his plotting and his plotting accuracy in spite of giving increasingly more time to communicating. At about 15 minutes into the experiment, he became aware of an overload, which he met by asking a vessel to "hold" while keeping up the plot. He employed "holds" seven times in all, consciously giving priority to the plot, yet still came close to finishing the complete exercise. He simplified his work by bunching work on cards and on models to minimize changing pens and said that, given time, he would have taped the two pens together. Perhaps his most significant remark was that he kept calm. He failed to follow up on the distress call beyond notifying the watch officer, and did not attempt to call the Sea Wench (the vessel with a radio outage).

Subject 3 fell farther behind in the experiment than did Subject 2. He, too, kept up his plotting time during the first half of the experiment, doing less plotting in the latter half. His final plot was the most accurate of all the subjects. He was the only subject who claimed that he did not feel overloaded at any time. His principal strategies were the use of "hold" (12 times) and dropping the plotting of tugs without tows. His first use of "hold" was in the seventh minute of the experiment, the earliest of anyone. His response to the distress call was more adequate than Subject 2's, including seeking additional information and trying to locate a vessel in the area who might help. He warned one vessel about a regulation on hawser length, something that no one else thought of. Like Subject 2, he did not attempt to call Sea Wench. His advisories were somewhat shorter (by 3.8 seconds on the average) than those of Subject 2, but he did not report shortening advisories as a means of meeting the traffic load.

3.4.6.2 Average Performers - Subjects 1,8,9 and 10 finished the exercise, but all at the expense of errors in plotting. Subject 9, with the best PI in the average group, fell behind in plotting early and admitted giving advisories off a plot that had not been updated in 30 minutes by the end of the experiment. He did not use "holds" to gain plotting time, but was considering it at the end.

Subjects 1,8 and 10 showed remarkably similar characteristics. Subject 1 did not use "holds", but shortened his messages by leaving out superfluous words and not initiating many messages. He also omitted routine advisories while plotting and prioritized his plotting (advancing vessels on the plot in the order of what he considered their importance). Subjects 8 and 10 used "holds" to gain some plotting time and gave relatively short advisories. Subject 8 ommitted call signs, prioritized advisories, and omitted advisories on meetings in traffic lanes. Subject 10 did not prioritize but omitted advisories on pre-calls. Subjects 1,8 and 10 all were aware that some of their advisories were in error.

Subject 4 kept up fairly well with the communications and plotting but completely omitted updating one vessel, yielding a high plotting error. He used "hold" a few (5) times, but did not omit or shorten advisories.

Subject 5 fell behind. He said his main concern was with the plot, yet his plotting error score was relatively high. He used abbreviations in marking card entries and relied considerably on memory in giving advisories.

3.4.6.3 Poor Performer - Subject 6 was clearly in trouble during the latter half of the experiment. Apparently he got behind in plotting during the early traffic buildup (second ten-minute period) and had to rely heavily on memory after that. His communications seemed to be unnecessarily long with too many questions on unimportant details. Although his number of communications was relatively low, this was partly a reflection

TABLE 3-3. SUMMARY OF STRATEGIES

	SUBJECT									
	GOOD		AVERAGE						SP	POOR
STRATEGY	2	3	9	4	1	10	5	8	7	6
REDUCING COMMUNICATING TIME										
Shortening Messages		X			X	X		X		
Omitting Messages					X	X		X		
Decreasing Number of Messages				X	X					X
Group Advisories			2			5	2	1	7	
REDUCING PLOTTING TIME										
Streamlining	X						X	X		
Omitting Traffic		X								
Neglecting Plotting			X		X					X
Asking for Help			L	M		L		M	E	L
TEMPORARY TRADEOFF										
Prioritizing Advisories								X		
Prioritizing Plotting	X				X					
Using "Hold"	7	12		5		5	7	8	19	4

X = Observed or reported.

E,M,L = Observed in early, middle, or late part of experiment.

Number = Number of times observed.

TABLE 3-4. INDIVIDUAL COMMUNICATING CHARACTERISTICS

Subject	PI	C	CIT	D	H
1	28.9	54	2	15.0	0
2	38.5	66	13	17.7	7
3	36.7	59	15	13.9	12
4	30.6	61	10	22.0	5
5	26.9	65	17	15.0	7
6	11.8	58	9	24.2	4
7	25.8	78	40	23.6	19
8	26.0	64	12	12.8	8
9	30.6	65	12	15.4	0
10	27.4	67	13	11.5	5

PI = Performance Index
C = Number of Communications
CIT = Number of Center (Subject)-Initiated Transactions
D = Average Duration of Advisories (seconds)
H = Number of "Holds"

of his being behind. He admitted that he "...let the plot go..." In real life he felt that he would have used "hold" much sooner; (his first "hold" was at 39 minutes, and he used "hold" only four times.) His performance in the face of an increasing traffic load might be characterized as "business as usual" in communications with consequent neglect of the plot.

3.4.6.4 Special Case - Subject 7 ranked next-to-last in the PI in spite of an accurate plot. His top curve in Figure 3-4, his C, CIT and D values in Table 3-4, and other observations combine to characterize him as excessively loquacious. He gave long advisories, initiated many extra messages, asked numerous questions - and consequently fell far behind in handling communication demands, his last VIT being 11 behind the next slowest subject. His strategy was to employ "holds," using a total of 19. Thus he might be considered effective with regard to the traffic he did service, but it is doubtful that in real life he could avoid an eventual critical traffic backlog unless he shortened procedures somehow.

3.4.7 Stress Measures

Since the buildup of demands on the subject watchstanders during the experiment was greater than is normally encountered in operations, the experiment was considered as a potentially stressful experience. To determine whether such stress can be measured and whether such measures relate to the quality of job performance, several measures were taken on some subjects at the beginning and at the end of the experiment. These measures included heart rate, blood pressure, rate of excretion of adrenalin in urine, and ratings of stress made by the subjects. Also samples of voice recordings of two subjects were rated for stress. The changes in the first four measures and the scores of the voice analyses are summarized in Table 3-5. Again the subjects are arranged from left to right in order of decreasing PI.

3.4.7.1 Physiological Measures - The rate of excretion of adrenalin, as measured in urine samples, has been found to be a reliable indicator of psychological stress (Ref.8). This measure increased between the beginning and end of the experiment for every subject from whom specimens were obtained.

The other stress measures were compared with adrenalin excretion and among themselves by computing coefficients of correlation. These correlations are summarized and explained in Table 3-6. Because of the small number of measurements involved, there is a risk that some of these coefficients of correlation were obtained by chance in spite of no real underlying relationship. With the numbers involved, any coefficient less than .67 based on 7 cases, or .55 based on 10 cases, could be expected to occur by chance in up to 10 percent of similar experiments; thus we consider values below those given to lack statistical significance. Using this criterion, we note immediately that systolic blood pressure correlated almost perfectly with adrenalin excretion, but that heart rate and blood pressure did not vary together significantly. These correlations suggest that the change in systolic blood pressure was a good indicator of change in adrenalin excretion (and thus of psychological stress), but that heart rate changes were of less value for stress analysis.

In Table 3-5, the adrenalin measures suggest that Subjects 2,5 and 8 experienced relatively little stress, Subjects 3 and 9 showed some stress, and Subjects 6 and 7 were the most stressed by the experiment. Blood pressure results tend to confirm this grouping, with the low stress group showing a drop in systolic blood pressure after the experiment. This lowering of blood pressure probably represents alleviation of initial apprehension about participating in the experiment.

Observations of behavior of the subjects confirm these conclusions. Subject 2, with the lowest adrenalin gain and a large drop in blood pressure, reported that, when traffic built up, he kept calm. Subject 5 appeared tense at the beginning of the experiment, with a jiggling leg and twitching thumbs, and he showed the largest drop in blood pressure of all the subjects. Subject 6, on the other hand, was obviously disturbed by the experiment, making comments on the absurdity of giving advisories from a plot 30 minutes out of date. His blood pressure (and heart rate) had increased far more than any of the others by the end of the experiment.

3.4.7.2 Stress and Performance - Increase in adrenalin excretion yielded a correlation coefficient of -0.62 with the PI. Although, based on only 7 cases, this result could occur 14 percent of the time by chance alone, we can give it credence, because blood pressure and PI had a coefficient of -0.59 based on 10 cases, with significance at the 8 percent level. We conclude, then, that there was a tendency for greater stress to

TABLE 3-5. STRESS MEASURES

STRESS MEASURE	SUBJECT									
	GOOD		AVERAGE						SP	POOR
	2	3	9	4	1	10	5	8	7	6
CHANGE * DURING EXPERIMENT										
Heart rate (beats/min.)	-6.3	5.5	-5.9	-0.7	-0.8	1.7	-4.4	-6.6	-8.0	14.2
Systolic blood pressure (mm.Hg)	-12	2	16	3	12	-17	-18	-4	16	38
Adrenalin excretion (nanogms/min.)	1.8	8.4	7.1				1.1	1.6	11.1	16.7
Stress rating score	5	1	0	3	6	1	2	2	-1	0
VOICE STRESS RESULT (average stress score)										
Early in experiment								1.7		1.9
Late in experiment								2.1		0.6

*A positive change indicates an increase.

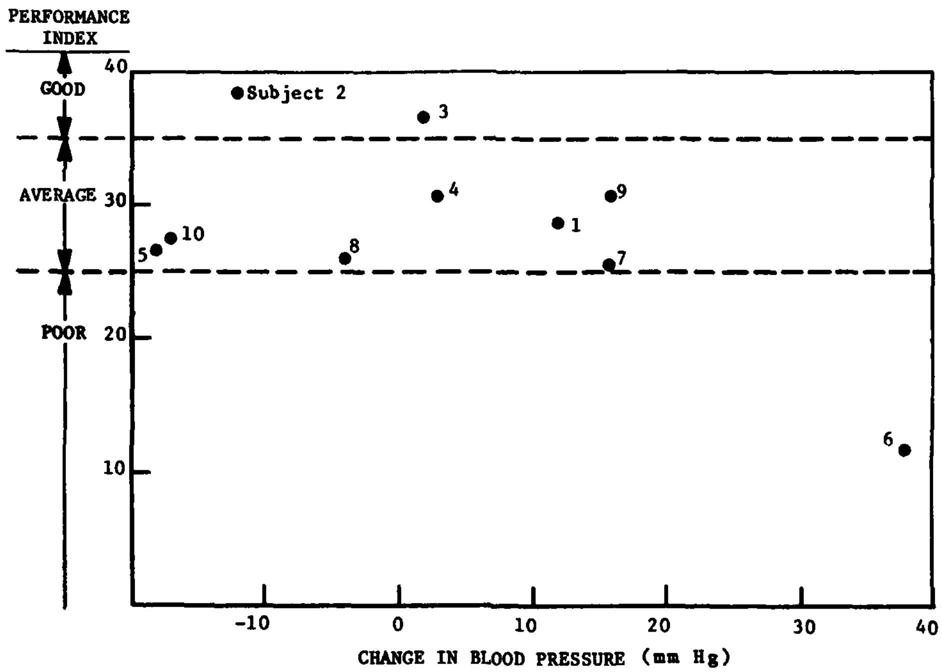

FIGURE 3-5. PERFORMANCE AND STRESS

TABLE 3-6. CORRELATIONS AMONG STRESS MEASURES

	B	H	PI	R	Number of Cases
A	.94*	.70*	-.62	-.65	7
B		.47	-.59*	-.35	10
H				-.13	10
PI				.44	10

A = Change in rate of excretion of adrenalin

B = Change in systolic blood pressure

H = Change in heart rate

R = Change in stress rating score

PI = Performance index

* = Statistically significant at the 0.10 level or better

Note: The coefficient of correlation is a measure of association between two sets of variables. A coefficient of 1.00 indicates that as one variable changes, the other changes in exactly the same way. A coefficient of -1.00 indicates that as one variable increases, the other decreases in exactly the same way. A coefficient of 0.00 indicates no relationship between the two variables.

EXAMPLE: Presently experiencing a headache:

X						
None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

1. Presently experiencing aching or burning eyes:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

2. Presently feeling tired, drowsy, having difficulty staying awake:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

3. Presently experiencing stiffness or tenseness:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

4. Presently feeling anxious, on edge, irritable:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

5. Presently experiencing a headache:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

6. Presently being fidgety:

None	Barely Notice-able	Slight	Mild	Moderate	Intense	Severe

FIGURE 3-6. STRESS RATING FORM

be associated with poor performance. Figure 3-5 illustrates this point graphically, showing that the conclusion is valid for Subjects 2,3,4,1,7 and 6, but not for Subjects 5,10,8 and 9.

3.4.7.3 Stress Ratings - As a part of the initial and final interviews, subjects were asked to rate their own feelings on 6 items that had been found to relate to stress in earlier studies (Ref.1,2,3,4). Each item could be rated on a scale from 0 (none) to 6 (severe) by simply putting an "x" in the appropriate box (see Figure 3-6). Each form was scored by adding the six values checked and dividing by 6.

The group had an average rating of 0.48 before the experiment, 0.80 after, in both cases between 0 (none) and 1 (barely noticeable), with an average increase of a mere 0.32 at the end. The highest rating checked by anyone on any item was 4 (moderate), used by Subject 2 for "tense" at the beginning and at the end of the experiment and for "anxious, irritable" at the end. A rating of 3 (mild) was used only 3 times, all at the end -- by Subject 1 for "fidgety" and Subject 4 for "tense" and "anxious, irritable". Certainly the subjects did not rate themselves as feeling stressed, either before or after the experiment.

The increases in stress ratings for all subjects are given in Table 3-5, and their correlations with other measures in Table 3-6. Although failing to meet the 10 percent criterion of statistical significance, the correlations with physiological measures of stress are all negative. That is, the more a subject was stressed by the experiment, the less likely he was to rate himself as feeling stressed. The calm subject (Subject 2) was probably the most candid. The severely stressed subject (Subject 6) rated all items 0 (none) both before and after the experiment, rapidly slashing his x's onto the form in a highly agitated manner. We interpret these results to mean that some of the subjects felt that they were on trial in the experiment, with a consequent anxiety and an unwillingness to admit it.

As would be expected, changes in stress ratings showed a small positive correlation with PI, the good performers being more secure in rating their feeling of stress.

3.4.7.4 Voice Stress - Samples of taped communications were selected for a subject with a low adrenalin gain (Subject 8) and one with a high gain (Subject 6). For each subject, six phrases were selected from the early part of the experiment, when the traffic load was light, and from later in the experiment, when traffic was heavy. The phrases were innocuous (e.g. "Seattle Traffic") so that content gave no clue as to stress. A professional voice analyst rated each sample in three different ways, using a scale ranging from 0 (no voice stress) to 5 (high voice stress). In all 72 ratings, 5 was used only once and 4 once. A rating of 3 was used 10 times with Subject 8, 8 times with Subject 6. The average ratings for the "early" and "late" communications for each subject are given in Table 3-5. These results are completely inconsistent with expectations. Subject 8 showed barely any increase in voice stress between the early and late samples, and Subject 6 showed a decrease. Furthermore, Subject 8, with the low adrenalin gain, had a higher voice stress average (1.9) than did the obviously stressed Subject 6 (1.3).

3.4.7.5 Summary of Stress Measures - Psychological stress associated with the conditions of this experiment was indicated by an increase in the rate of excretion of adrenalin during the experiment in all subjects. There was some tendency for people with higher stress scores to perform more poorly than those showing less stress. Changes in systolic blood pressure correlated well with the adrenalin scores; changes in heart rate showed no significant correlation with blood pressure, but some relationship to the adrenalin scores. Subjective ratings of stress had low negative correlations with the physiological measures, which, together with observations of the subjects' behavior, suggested that only the relatively unstressed, good performers were secure enough in the test situation to give candid estimates of their feelings. Analysis of voice stress failed to show any evidence of the stress evidenced by physiological measures and observations.

3.4.8 Job Satisfaction

As a part of the preliminary procedure, each subject was asked four questions regarding job satisfaction: Do you like working here? Is VTS a good career assignment? Would you like another tour at this VTS? Would you like a tour at another VTS? These questions had been asked previously at Puget Sound VTS as well as at other VTSs

(Ref.5) and were repeated at this time to see whether attitudes had changed over the previous 16 months. The responses are summarized in Table 3-7 together with responses at Puget Sound and across four VTSs in 1978-79.

Obviously these watchstanders enjoy their work. Their reasons (the people, doing a unique and useful job, shore duty) are the same as those given previously in other VTSs. Although the number of cases in each sample is small (10 in 1979, 6 in 1978), the job attitude at Puget Sound VTS appears to have improved. In both 1978 and 1979 there were 3 watchstanders who would not want a second tour at Puget Sound, but there were 7 in 1979 who said they would like another tour as compared to 1 in 1978. Whereas in 1978, Puget Sound VTS had proportionately fewer watchstanders who said they would like a second VTS tour than did the four VTSs combined, the proportions in 1979 in favor of more VTS work was far higher than for the combined four in 1978. The question on a tour at another VTS yielded essentially the same results. This improvement in job attitude at Puget Sound VTS is probably the result of a combination of changes, including giving more responsibility to non-commissioned officers, simplifying the plotting, and changing watch and rotation schedules.

The highest number of negative replies was to the question of VTS as a career assignment. Although fewer than in the four VTSs in 1978, still 4 out of the 10 subjects felt that radarmen and quartermasters on VTS duty would have lost some proficiency in their career fields ("You get behind everybody else".) on returning to sea duty. Three of the 4, however, stated (as did many in other VTSs in 1978) that they could consider VTS a good career if it were a "rate".

3.5 DISCUSSION OF RESULTS

3.5.1 Representativeness of Results

Throughout the following discussion, it is important to make the following distinction: the performance of watchstanders in this experiment does not represent what might be expected to happen in real-life operations at the Puget Sound VTS, but does represent what might be expected under conditions like those of the experiment.

The simulation differed from real-life operations at Puget Sound VTS in at least five significant respects. First, there are always other people in the operations room who can help a watchstander in plotting when the workload is heavy. Our experiment denied this assistance, although we asked the subjects to request it, and six subjects did. Second, in spite of instructions to do what would be done in real-life operations, some of the subjects probably tried to guess what the experimenters were evaluating and assigned priorities to their tasks based on their guesses. For example, a subject expecting to be rated on thoroughness would initiate more requests for additional information than he would normally do in operations, to the neglect of the plot. Third, our lack of detailed knowledge of the realities of Puget Sound traffic introduced little discrepancies in the simulation that might disturb a watchstander's work pattern. For example, additional questions were raised by some watchstanders regarding a simulated cargo different from the one that a particular vessel regularly handled. Fourth, some of our initial reports omitted information that a vessel would normally provide, necessitating additional subject-initiated queries. Finally, the experimental situation was stressful in varying degrees to the individual subjects. In spite of assurances that they were not being evaluated as individuals, they were apprehensive at being closely observed and recorded. In summary, then, the simulated operation differed from real operations at the Puget Sound VTS, and the errors in plotting and in advisories that occurred during the experiment would not be expected under similar traffic loads in actual operations there.

On the other hand, the various ways in which the subjects reacted to the increasing traffic load are very likely indicative of how they would react under the same circumstances in real-life operations. The subjects appeared to be well-motivated. They were cooperative and seemed to be genuinely concerned with performing their duties well under trying circumstances. Their behavior was professional. Although some showed physiological indications of stress, they were all calm and courteous in their communications, even in response to annoying comments. We feel justified, then, in drawing some general conclusions about the strategies they adopted to cope with unusual conditions.

3.5.2 The Need for SOP

The real challenge of the experiment was to effect a tradeoff in allocation of time between communicating and plotting that would minimize delays in meeting user vessel needs and still allow time to keep up an accurate plot. Figure 3-4 shows graphically that as time given to communicating increased, time given to plotting decreased proportionately, and vice versa. However, Table 3-3 shows equally clearly that the techniques adopted for effecting the tradeoff varied considerably from person to person. This variability should be of concern, for it is evidence of a need for firmer standing operating procedures (SOP) for responses to emergencies.

In selecting the performance index to reflect both keeping up with incoming communications and maintaining an accurate plot (Section 3.4.3.1), we essentially judged that it is better to keep mariners waiting for service than to risk giving erroneous advisories. Putting callers on "hold" to permit updating the plot was used by 8 of the 10 subjects, with varying degrees of effectiveness, Subject 7, who utilized "hold" 19 times but fell far behind all other subjects because of too much talking, clearly illustrates that "hold" must be combined with <u>other</u> strategies to be effective. The "other" strategies involve either shortening communications or plotting faster. <u>There are inherent dangers in both techniques</u>. When a watchstander must shorten communications under pressure, there is no guarantee that the information judged as relatively unimportant is truly unimportant. Many serious accidents have occurred because someone omitted usually trivial information that one time when the information was critical. Likewise, any simplification of the plotting process adopted arbitrarily under stress places safety wholly on the unguided judgment of the watchstander.

The only way to insure against loss of critical information when the system is stressed is to determine beforehand what procedures carry the least risk and to be certain that <u>all</u> watchstanders understand and follow the prescribed procedures. That is, SOP <u>must</u> be established, and watchstanders must be thoroughly trained in the SOP.

It is beyond the scope of this study to recommend what procedures should be adopted. Every VTS needs different SOP, which must be developed by the local operations staff, who are familiar with all aspects of the operational situation. All options for coping with heavy traffic loads, accidents, and other unusual events must be evaluated. No procedure should be adopted that involves reduction in the information being processed until thorough study has been made of the risks involved in eliminating that information. Once the optimal procedures have been defined, they should be written clearly, concisely and explicitly and promulgated as SOP.

Adopting SOP is not enough. Every watchstander must demonstrate an understanding of the SOP and the ability to follow SOP under routine and emergency conditions. A program of training and evaluation in SOP is needed, not only to qualify trainees for standing watch, but regularly to refresh qualified watchstanders. Group exercises in simulated emergencies should supplement individual study and testing, for the purpose of the effort is to assure a smoothly functioning team under all operating conditions.

The foregoing remarks are not intended to imply a lack of SOP and training in VTSs. All VTSs, operational or preoperational, have SOP and have training programs. However, our observations have convinced us that all VTSs are still weak in their anticipation of, and preparation for response to, unusual circumstances. Every VTS needs to study the ways in which emergencies and heavy workloads can affect operations, to determine and specify as SOP the preferred strategies for coping with these situations, and to train and exercise all personnel to assure uniform and effective response to unusual events. The experiment reported here clearly demonstrated the inherent dangers of leaving emergency responses up to the ingenuity and judgment of a stressed watchstander. Although the Puget Sound watchstanders were chosen to demonstrate typical reactions to overload, we are confident that a similar variety of responses would have been found among the personnel of any VTS.

3.5.3 Additional Findings

3.5.3.1 Stress Evaluation - in general, the subjects who showed relatively little physiological stress (as measured by adrenalin excretion) were best able to meet the demands of the experimental situation. Perhaps keeping calm helped. This reinforces the conclusion that SOP and training are needed; for an important element in calmly

TABLE 3-7. RESPONSES TO INTERVIEW QUESTIONS

QUESTION		Number	Percent		
		PS '79	PS'79	PS'78	4 VTSs, '79-'78
Do you like working here?	Yes	10	100	50	59
	No	0	0	17	30
	No reply or unsure	0	0	33	11
Is VTS a good career assignment?	Yes	6	60	33	36
	No	4	40	67	52
	No reply or unsure	0	0	0	12
Would you like another tour at this VTS?	Yes	7	70	17	46
	No	3	30	50	41
	No reply or unsure	0	0	33	13
Would you like a tour at another VTS?	Yes	8	80	17	48
	No	2	20	50	40
	No reply or unsure	0	0	33	12

meeting stressful conditions is knowing exactly what to do and how to do it.

With regard to methodology, the results suggest that blood pressure is a potentially valuable indicator of stress that can be readily measured while watchstanders are on duty. Pulse rate appears to be a less precise indicator, and analysis of voice recordings apparently is not sensitive to the kinds and levels of stress of concern in VTS operations. In a study of voice stress in space operations, NASA arrived at a similar conclusion (Ref.9). Subjective ratings as used in the experiment were completely unreliable for indicating stress. Subjective ratings have been found to be useful in the evaluation of aircrew workload and fatigue (Ref.10); however, considerable effort must be expended in developing an appropriate scale and in training subjects to use it before reliable results can be expected.

3.5.3.2 Job Satisfaction - The subjects of this experiment liked VTS work, and the level of satisfaction was higher than it had been at PSVTS, and VTS-wide, the previous year. Changes in procedures and policy at PSVTS have apparently been effective in raising morale. Very likely the establishment of "pro pay" has been a significant factor in improving job satisfaction VTS-wide. There are still watchstanders who feel that a VTS assignment does not advance a career as a radarman or quartermaster.

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